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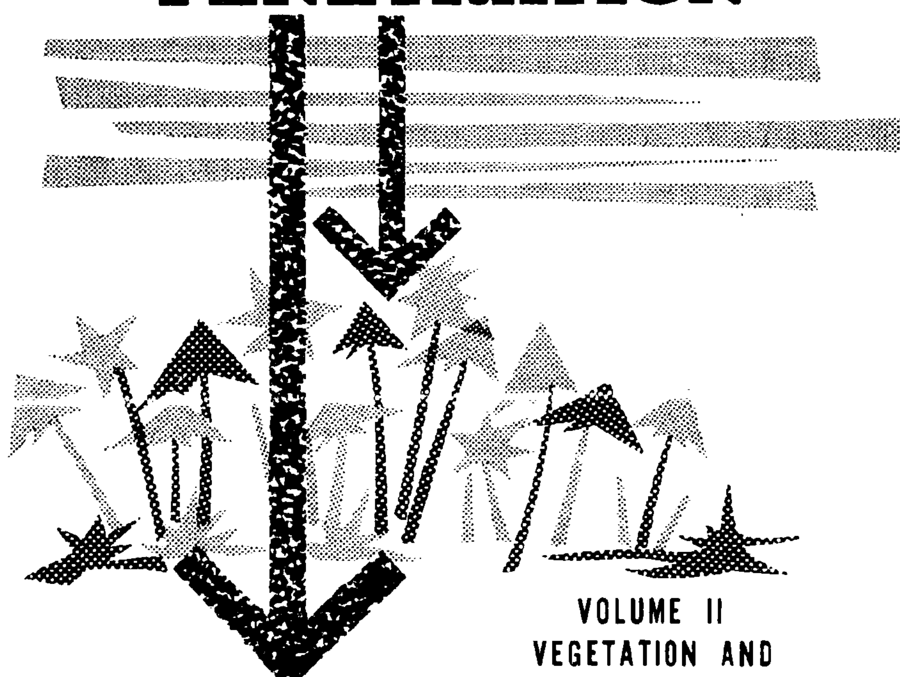
JUNGLE CANOPY PENETRATION



VOLUME II
VEGETATION AND METEOROLOGICAL STUDIES

Bendix SYSTEMS DIVISION OF THE BENDIX CORPORATION

BSC 36175

JUNGLE CANOPY PENETRATION (U)

FINAL REPORT

VOLUME II

VEGETATION AND
METEOROLOGICAL STUDIES

PREPARED FOR

THE DEPARTMENT OF THE ARMY

CONTRACT No. DA-42-007-530

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THE Bendix CORPORATION
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PREFACE

The Jungle Penetration field program was conducted primarily to describe and define the ventilation processes of the rain forest. As a means to this end an aerosol tracer technique was used. Fluorescent zinc cadmium sulfide, which approximates a true aerosol, was released above the forest and its concentration above and below the canopy measured during the succeeding hours. A description of the observed ventilation processes is presented in Volume I of this report. Two relevant but subsidiary data collections were also performed. First a complete survey of the vegetation was performed in the immediate vicinity of the test array. Secondly a collection of various types of meteorological data was taken within the test array. The results of the vegetation study are contained in Part I of this volume. The meteorological data provide the basis of a detailed climatological report which is presented in Part II of this volume.

ACKNOWLEDGEMENT

The Bendix Corporation gratefully acknowledges the cooperation and courtesies extended by the government of the Republic of Colombia during the Jungle Canopy Program. The operation of a program of this nature in a foreign country without the enthusiastic assistance from the government of that country would present insurmountable difficulties.

By working through the United States Department of State, the United States Embassy in Bogota, and the Inter-American Geodetic Survey with headquarters in Ft. Clayton, Canal Zone, arrangements were made with the Augustin Codazzi Instituto Geografico of Bogota, Colombia to allow the project to enter Colombia under an existing agreement between the United States government and the government of Colombia covering the survey work being done by the Inter-American Geodetic Survey.

Without this cooperation and the subsequent assistance rendered by Mr. James Haahr, the American Consul in Medellin, the Maderas del Darien Ltda., and the Gratuitous assitance from numerous Colombians in Medellin, Turbo and Chigorodo the successful completion of the project would have been impossible.

It is appropriate to acknowledge those who participated in the several phases of the program. Workers in the field included Harold W. Baynton, Alan L. Cole, Gerald C. Gill, George J. Leszczynski, James W. Mair, Reinhardt Mittelstadt, Allan Ramrus, and G. H. Spence. In addition to these, W. Gale Biggs, Fred W. Brock, E. Wendell Hewson and Paul E. Sherr made major contributions to the data analysis and interpretation.

VOLUME II

PART I

VEGETATION CHARACTERISTICS OF THE RIO LEÓN TEST AREA

A study of the Rio León test area by Dr. Stanley A. Cain, consultant to the project

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SECTION 1

THE HUMID TROPICS

Rain forest is one of a small number of world climatic types. It occurs in the humid tropics where constant high temperatures and moisture favor the growth of the tall broadleaf trees that dominate the vegetation. It is of interest to note briefly and in a general way where the humid tropics occur in the world.

This question is looked into from two sides in a recent article by Fosberg, Garnier and Küchler in THE GEOGRAPHICAL REVIEW [1]. The mapped result of these inquiries is reproduced with the permission of THE GEOGRAPHICAL REVIEW in Figure 1-1.

1.1 CLIMATIC CRITERIA

Garnier states: "To summarize, then, the humid tropics can be defined as the area where (1) the mean monthly temperature for at least eight months of the year equals or exceeds 68°F. (20°C.); (2) the vapor pressure and relative humidity for at least six months of the year average at least 20 millibars and 65 percent respectively; and (3) the mean annual rainfall totals at least 40 inches (1000 millimeters), and for at least six months precipitation is 3 inches (75 millimeters) each month."

Garnier examined and rejected the air-mass parameter as an approach to mapping where the atmosphere's physical properties change strongly over a short distance. The procedure he adopted is the reverse of that. He asked himself what conditions constitute humid tropicality and how long each year such conditions must occur for an area to be considered to lie within the humid tropics. His criteria are summarized in the above quotation and the areal results are shown on the upper map on Figure 1-1. Five subtypes are defined by a combination of primary and secondary criteria.

The cross-hatched areas have 12 months with mean monthly temperature 68°F or more, mean relative humidity 65 percent or more, and mean vapor pressure 20 mb or more. The stippled areas have 8 to 11 months with mean monthly temperature 68°F or more, mean relative humidity 65 percent or more, and 6 to 11 months with mean vapor pressure 20 mb or more. Otherwise stated, these areas have 1 to 4 months in which the temperature and relative humidity are less than in the first case, and 1 to 6 months in which the vapor pressure is less. Secondary criteria concern rainfall. Type 1 (darkest shading on the map) has a mean annual rainfall of over 40 inches and no month with less than 3 inches; type 2 (median shading) has a mean annual rainfall of over 40 inches, and 1 to 6 months with a rainfall average of less than 3 inches; type 3 (lightest shading) has a lower mean annual rainfall and not fewer than 6 months with 3 inches.

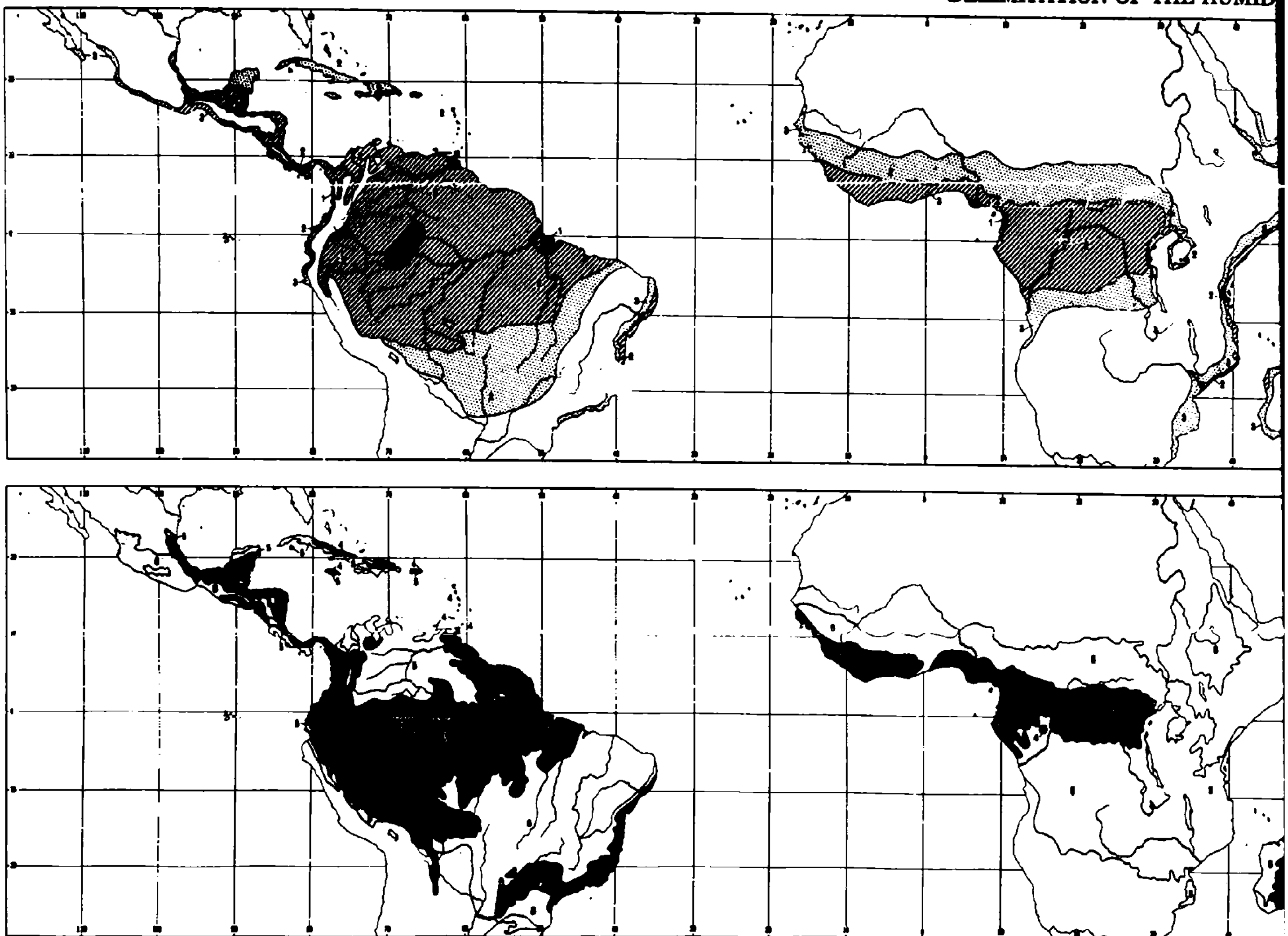
Questions can be raised as to whether meteorological data in many parts of the tropical world are adequate to determine valid boundaries, and whether Garnier selected the most significant meteorological parameters. In any case, he shows, in so far as data permit, and on the basis of his selected criteria, the outer (poleward) limits of equatorial regions where humid tropicality occurs regularly and, within that broad zone, where it occurs seasonally.

1.2 VEGETATION CRITERIA

Küchler does not use meteorological data but a sort of "bioassay." His delineations shown in the lower map on Figure 1-1, are based on the relative absence or paucity of xeromorphic features of the vegetation, such as deciduousness, i.e., periods of the year during which trees are leafless, presumably because of dryness. One type (number 4 on the map; areas of dark shading) is more or less permanently humid and tropical. The prevailing vegetation is tropical rain forest composed largely of broadleaf evergreen trees with many epiphytes. Near the borders of this type there may be an admixture of deciduous species of trees and/or patches of grassland. The other type (number 5 on the map; areas of light shading) has alternating humid tropical and dry tropical months. The periodic dryness is reflected in the occurrence of tropical semideciduous forests where the dry period is relatively short, or in tropical deciduous forests with relatively few epiphytes and/or savannas (grasslands with some trees), or some combination of these types, where it is long.

1

DELIMITATION OF THE HUMID

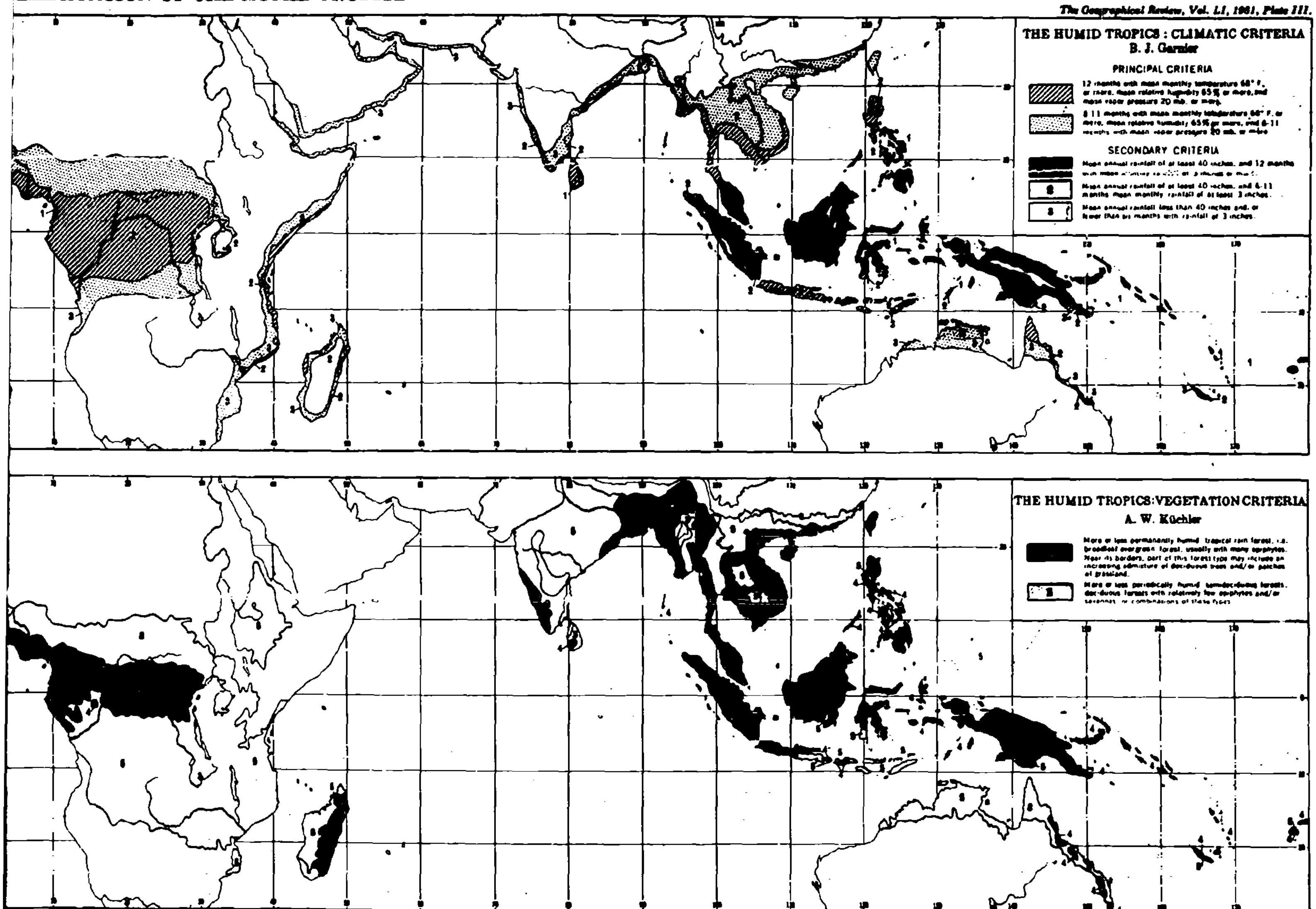


SCALE 1:80,000,000
CYLINDRICAL EQUAL AREA PROJECTION

Figure 1-1

)ELIMITATION OF THE HUMID TROPICS

The Geographical Review, Vol. LI, 1961, Plate III.



SCALE 1:60.000.000
CYLINDRICAL EQUAL AREA PROJECTION

Litho. A. Hoen & Co., Baltimore, U.S.A.

Figure 1-1 Delimitation of the Humid Tropics Based on Climatic and Vegetation Criteria

1.3 COMMENT ON THE WORLD MAPS OF THE HUMID TROPICS

The test site in northwestern Colombia certainly lies within the humid tropics. According to Garnier the area is type 2: tropical, with the humid year interrupted by one to six months with less than 3 inches of rainfall. * According to Küchler the area is type 4; tropical and more or less permanently humid; but not far to the east occurs type 5 in which the forests have a more pronounced deciduous element, fewer epiphytes and some savanna or tropical grassland. Both of these types connect with the massive areas of the Amazon basin to the south and east and with Panama and the rest of Central America to the northwest. The maps adequately show the occurrence of these types in tropical Africa and Asia.

The two maps deal with the same two phenomena: tropicality and humidity, one directly, the other indirectly. They do not correspond in many parts in the world. The discrepancies are due in part to the small scale of the maps and the paucity of meteorological and vegetational data, in part to the complexity of vegetation and to the multiplicity of meteorological (and other) conditions to which it responds. Both maps have made great demands on the judgment of the authors: in one case in the selection of climatic parameters, in the other in the selection of vegetational characteristics used as "indicators" of humid tropicality. Fosberg concluded that in matters of synecology (and biogeography) Küchler's map is more useful, and that Garnier's map will have more usefulness from the viewpoint of human ecology. Because most of the phenomena dealt with are overlapping phenomena, in most parts of the world without sharp boundaries, boundaries on maps may vary according to compromises and selections of criteria. The criteria employed by the investigator are determined by the purpose of the map. The areas delineated as a consequence show what has been selected for emphasis, and the areas are natural only with regard to the selected criteria.

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*Mean rainfall data for the area are given in Table 1-1. Part II of this volume.

SECTION 2

THE NATURE OF TROPICAL RAIN FOREST

In 1952 P. W. Richards[2] brought together for the first time what was known about the ecology of that important worldwide vegetation type of the humid tropics (except for the general discussion of the formation by Schimper).[3]

Schimper defined tropical rain forest as "Evergreen, hygrophilous in character, at least 30 m high, but usually much taller, rich in thick-stemmed lianas and in woody as well as herbaceous epiphytes." In a strict sense the term rain forest would not include the seasonal types of tropical forest where a dry season imposes a semi-deciduous and deciduous aspect (monsoon types) and tropical savanna and thorn forests.

Cain and Castro give a general description of the tropical rain forest.[4] Of the optimum formation series or true rain forest they write: "The type of vegetation known as true rain forest is arranged in three or four layers of woody plants, but the uppermost layer of 'outstanding' or 'emergent' trees may not occur, as in the rain forest of French Guiana. The dominant trees usually have long clean trunks which are 20 to 30 m to the first branches. The crowns are comparatively small. Such deciduous elements as may occur are completely unimportant in the vegetation as a whole. Although compound leaves may be abundant in the upper strata, simple leaves of mesophyll size are usually dominant in all tree layers. Buttressing, the presence of palms and tree ferns, and an abundance of lianas are not diagnostic but may occur in varying degrees; and special features such as stilt roots, pneumatophores, thorns and spines, cauliflory, and low-growing epiphytes are of no particular significance for the type, although they may be present in varying degree. The true rain forest is the high forest of the constantly humid tropics."

Recently Beard[5] described a classification of American vegetation-types using the following types of vegetation:

A. Optimum Formation

1. Rain forest

B. Seasonal Formations

1. Evergreen seasonal forest
2. Semi-evergreen seasonal forest
3. Deciduous seasonal forest
4. Thorn woodland
5. Cactus scrub
6. Desert

C. Montane Formations

1. Lower montane rain forest
2. Montane rain forest or cloud forest
3. Montane thicket
   a. High mountain forest
4. Elfin woodland or mossy forest
5. Paramo
6. Tundra

D. Dry Evergreen Formations

1. Dry rain forest
2. Dry evergreen forest
3. Dry evergreen woodland and littoral woodland
4. Dry evergreen thicket and littoral thicket
5. Evergreen bushland and littoral hedge
6. Rock pavement vegetation

E. Seasonal-Swamp Formations

1. Seasonal swamp forest
2. Seasonal swamp woodland
3. Seasonal swamp thicket
4. Savanna

F. Swamp Formations

1. Swamp forest and mangrove forest
2. Swamp woodland
3. Swamp thicket
4. Herbaceous swamp

In this classification only mature, stable and integrated communities (climax communities) are dealt with and the formations are characterized by structure and physiognomy, not by floristic characteristics. The formation groups, B through F, can be conceived of as radiating from the central optimum formation or true rain forest as series of structurally related formations decreasing in stature and complexity in response to important climatic and edaphic conditions as they shift from the optimum toward the pessimum. The formation series, then, are habitat groupings. Within the formations the associations would be distinguished on a basis of floristic, not structural, features. The system is not applicable to strongly disturbed vegetation.

True rain forest has been little studied in South America. The most recent and one of the most informative studies is that of Schultz[6]. Earlier studies include those by Davis and Richards[7, 8], Beard[9], Fanshawe[10], and Cain, et al[11]. These few studies agree pretty well in their descriptions of the true rain forest. The following notes on the forest in the vicinity of the test site, Rio León, Antioquia, Colombia, concern features characteristic of this forest. Any significant departure from the general characteristics of true rain forest will be remarked on.

2.1 THE FOREST CANOPY

The top of the forest does not form a plane surface as is characteristic of temperate forests, but an undulating one. The description by Schultz for Surinam fits the situation at the León site: "The canopy dominants tend to occur in groups between which the crowns of trees of species of the lower story form the continuation of the canopy." The exception to this that occurs in some types of rain forest is the presence of true emergent species which lift their complete crowns above the general level of the forest top. Such emergents are absent at the León site and the semi-emergent clumps of trees, which reach to 155-160 ft, tend to consist of two to several trees of different species.

The crowns of the larger trees seem to be rather small in proportion to the size of the trunk, and they tend to be somewhat wider than they are deep. True emergents sometimes have crowns very much wider than deep, and may be described as umbrella-shaped. At the León site the largest crowns of the tallest trees were about 55 x 35 feet and were not really umbrella-like, but more like oblate spheroids. (Here it should be said that all tree crowns tend to be more irregular than such descriptions would suggest and most of the foliage is to be found at the upper and outer periphery of the crown where light is brighter. A considerable part of the interior foliage is not formed by the crowns of the trees, but by the lianas and epiphytes perched on the upper branches. The large lianas often reach as high as the tallest trees and intermingle their foliage with that of the trees.)

2.2 STRATIFICATION OF THE FOREST

Temperate forests and disturbed forests of many kinds tend to show readily apparent structural layers. These may be marked by the mature height of component species or by even-aged classes of certain species that have developed after disturbance. In true rain forest no well-marked readily distinguishable tree strata occur, and the grouping into superior strata, intermediate strata, etc., is largely arbitrary. If enough height measurements of the more abundant species of a rain forest are made, the existence of strata based on inherent characteristics of the species can be demonstrated. This is the case in undisturbed rain forest, but the existence of such layers is obscured by the transgressive individuals of species destined for the superior stratum. Such mature and undisturbed forests are all-aged, not even-aged, and most species can be found at all heights from seedlings to old standards.

Below the upper, middle and lower strata of trees (granting a certain arbitrariness in this designation) there are at least two other fragmentary but evident layers. One is composed of shrubs and semi-shrubby species, often about 6 ft high, and the other is made up of a usually thin scattering of herbaceous plants of lower stature. Even in these layers the majority of the vegetation is formed by tree reproduction and the low ground cover often consists solely of tree seedlings.

Lianas are usually assigned to the highest layer to which they reach as they climb on, or break loose and are suspended from, the trees. Epiphytes also are assigned to the layer in which they occur, attached to tree trunks and branches, irrespective of their stature as individual plants.

2.3 TREE FORM

A conspicuous feature of many rain forest trees is the almost columnar trunks of the larger specimens, unbranched and undistorted, often to heights of 100 ft or more. Accompanying this feature is the fact that the tallest trees often have a d.b.h.* of a mere three feet. The combination of these two characteristics in some rain forests gives the impression of a forest of straight poles of spectacular height. While this feature is present at the León site, it is obscured by the density of the undergrowth. This point can be substantiated by reference to logs of cotibo that were removed from the vicinity of the Bendix camp on the Rio León, as shown in Table 2-1. Since the trees were cut down by axe, (it was said that chain saws were not used because of the gummy sap of cotibo) the logs of larger butt diameter include some butt swell. Also, no logs were taken out of the woods from parts of the tree trunk with branches. Still, clear logs of 60 to 80 ft length were common.

2.4 TREE BASES: BUTTRESSES, STILT-ROOTS AND STRANGLERS

The rain forest is the only vegetation area in which pronounced tree buttresses are characteristic, although they may be scarce in some stands. In general, buttressing is an inherent characteristic of tree species whose occurrence is limited to tropical rain forest. The most conspicuous form is that of the plank buttress, shown in Figure 2-1. Eleven species of trees in the vicinity of the León site were observed to have moderate-to-pronounced plank buttresses. Cain and Castro (loc. cit.) refer to one specimen of Ceiba Pentandra with numerous planks extending out from the trunk to 10-20 m and up the trunk to a maximum height of about 10 m. This was on the Rio Capim, Para, Brazil. No such elaborate buttressing was seen along the Rio León, but many trees seem spectacular to persons familiar only with temperate forests.

Trees may be seen standing on stilt-like roots in many humid forests of the world because the seedlings long ago had germinated on logs which had subsequently decayed away. In the rain forest, however, there are usually some species of trees which inherently have stilt roots. Figure 2-2 shows an azeite with such a system that is rather elaborate.

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*Diameter breast high, measured 4 1/2 ft above the ground.

TABLE 2-1

DIMENSIONS OF SOME LOGS OF COTIBO CUT IN THE

FOREST NEAR THE LEÓN CAMPSITE

Butt Diameter (Inches)	Top Diameter (Inches)	Log Length (feet)
39	24	61
37	21	63
36	24	68
36	20	68
47	24	68
43	25	73
39	24	68
32	21	55
33	21	40
40	30	53
46	32	58
39	22	49
38	27	46
34	22	66
57	30	61
38	24	49
47	28	49
36	22	48
36	23	46
37	28	72
38	20	72

TABLE 2-1 (CONT.)

30	25	47
48	20	81
36	19	57
43	22	65
27	20	44
40	24	46
32	22	46
29	20	38
50	32	46
31	22	51
38	24	42
32	26	48
33	20	68
49	31	65
48	26	62
43	23	52
40	21	53

Figure 2-1 Example of Buttress Root System, León Test Site

Figure 2-2 Example of Azeite With Stilt Root System. León Test Site

One species of strangler tree was rather frequent in the Rio León forest, a species of Ficus. Germinating on branches of other trees, stranglers send down an intricate array of intertwined and anastamosing roots. Such species frequently kill off the "host" trees by over-growing them. One observed specimen had established itself about 50 ft. above ground on a cetibo.

2.5 LIFE-FORM CLASSES

More than half a century ago the Danish botanist Raunkiaer developed a system of life-form classification of plants that has been widely used because it is subject to statistical treatment and the resulting life-form percentages correlate with major climates and world vegetation types. The major life-form classes are based on the degree of protection afforded the perennating buds of the plants. According to this classification phanerophytes are trees and shrubs whose buds are lifted well above the ground. This class is subdivided into megaphanerophytes, trees taller than 30 m; mesophanerophytes, trees 8 to 30 m tall; microphanerophytes, trees 2 to 8 m. tall; and manophanerophytes, shrubs 25 cm to 2 m tall. The theory is that the taller plants are more exposed to the elements and that this is important during times of stress, such as coldness or dryness. Details of these and other classes can be sought in many places, including Cain and Castro's Manual (loc. cit.), and are not pertinent to the present discussion. It is perhaps sufficient to point out that the "phanerophytic climate" is characteristic of rain forest and is marked by a high percentage of phanerophytes, especially of the taller subclasses. This can be illustrated by a 2 ha plot in rain forest at Mucambo, Belem, Para, Brazil (Cain, et. al, 1956) on which of the 218 species 162 or 74 percent were phanerophytes. Of the total flora 22.5 percent were megaphanerophytes, 39.5 percent were mesophanerophytes and 62 percent of all species were tall trees.

Table 2-2 shows that 21 species of trees exceed 30 m in height (out of the 56 species on the sample plots for which both height and leaf-size class data were available) and are megaphanerophytes, and that 25 species are mesophanerophytes. Data are not available on the total flora, including lianas, epiphytes, shrubs and herbs, so it is impossible to say what percentage the phanerophytes are of the total flora, but it certainly is high-and typical of rain forest.

TABLE 2-2

RAUNKIAERIAN LEAF-SIZE CLASSES OF PHANEROPHYTES, RIO LEÓN, ANTIOQUIA, COLOMBIA: NUMBER AND PERCENT

Leaf-size classes	Phanerophytes			Total
	Mega-	Meso-	Micro-	
Leptophyll				
Number	0	1	0	1
Percent	0	4.0	0	1.8
Nanophyll				
Number	0	1	0	1
Percent	0	4.0	0	1.8
Microphyll				
Number	3	2	0	5
Percent	14.3	8.0	0	9.0
Mesophyll				
Number	13	17	8	38
Percent	61.9	68.0	80.0	67.8
Macrophyll				
Number	5	4	1	10
Percent	23.8	16.0	10.0	17.8
Megaphyll				
Number	0	0	1	1
Percent	0	0	10.0	1.8
Total				
Number	21	25	10	56
Percent	37.5	44.6	17.9	100.0

2.6 LEAF CHARACTERISTICS

Most students of the rain forest have pointed out the prevalence of the mesophyll leaf-size class (area between $9^2 \times 25$ sq mm and $9^3 \times 25$ sq mm), the fact that the leaves and leaflets usually have entire margins, and that the texture is firm to semi-coriaceous. Cain et al (loc. cit.) found that in the rain forest at Mucambo 68 percent of the leaves were in the mesophyll leaf-size class and that for mega- and mesophanerophytes it was 75 percent. Trees at the León site seem to be about 68 percent mesophyll in size, as is typical of the rain forest.

Among the trees at the León site, all leaves were entire-margined except for one species and there was an almost even division between trees with simple leaves and those with variously compound leaves, i.e., with leaflets or deep lobes. A novel feature of rain forests is the large number of leaves and leaflets that have "drip points" which are slenderly attenuate and have relatively long tips. This feature is common in the forest around the León site. Old leaves soon become covered, especially on the upper side, with a more or less continuous coating of epiphyllous mosses and liverworts of small size, with which are mixed some microscopic algae and fungi.

Most of the tree species are evergreen. Leaves tend to hang on for more than a year, sometimes for a few years. New leaves seem to "flow" out of the bud in a limp and sometimes colorful form, and to enlarge rapidly. At the León site there were only one or two species that were deciduous by mid-January but six deciduous species were observed by early February. The deciduousness is not pronounced in this forest, and it is of short duration. In some cases new leaves started to appear within two weeks after the old leaves had been shed, and only in extreme cases, so the local people said, were trees deciduous for as long as two months. This period of leaflessness that affects only a small part of the forest is correlated with the short season when the rainfall falls below three inches a month.

2.7 FLORISTIC RICHNESS OF THE RAIN FOREST

Rain forest is usually very rich in species. The Mucambo plot in the Lower Amazon, referred to before, had 173 species of trees on about five acres and at Castanhal the number was 149. Sample plots indicate the woody flora is not as rich at the León site where a hectare has about 70

species of trees. Transect No. 1 had 22 species on 0.3 acre, transect No. 2 had 24 species on 0.5 acre, and the line plots had 30 species (these were 10 in. d.b.h. and over) on 1.4 acres.

Only under exceptional edaphic conditions does tropical rain forest have dominance. In this sense "dominance" means that one or a small number of species makes up a majority of the coverage or the volume of the timber present. To speak of dominance in temperate forests often means that the single or small number of species composes 80 percent or more of the vegetation, at least in the superior layer of a forest. In humid tropical forests the approach to dominance is at a much lower percentage even when it occurs on soils that are physically or chemically extreme. The forest between the Rio León and the Rio Atrato is a flood-plain forest occupying hydromorphic soils in a filled valley. The fact that the water table is near or at the surface of the ground for much of the terrain for perhaps 9 to 10 months of the year has the effect of excluding many species from it. On the other hand, local conditions apparently favor olleto, caracoli and, especially, cotibo. In fact lumbermen refer to this region as the cotibo belt. Here we are dealing with true rain forest, where there is collective dominance by these three species.

Lianas are abundant in the forest around the León site. They include some small and delicate forms that do not climb far above the ground, and numerous species that reach to the top of the tallest trees. Some of the latter have stems 8, 10 and 12 inches thick with heavy bark.

Epiphytes range from small mosses and liverworts occurring at all levels to herbaceous and even woody varieties perched on the upper branches of tall trees. The presence of filmy ferns (membranaceous Hymenophyllaceae) on the lower stems of small trees and bushes is an indication of high relative humidity. Some of the epiphytes of the tree crowns (Orchidaceae, Bromeliacae) are xeromorphic and probably xerophytic. At least their fleshy or leathery leaves are apparently adapted to withstand periodic water-deficit stresses. A large number of the fairly abundant epiphytes belong to the Araceae, a family which includes many familiar house plants such as Philodendron and Monstera.

Although both lianas and epiphytes are abundant in this vegetation, and are of types usually found in the rain forest, neither life-form group approaches the great abundance they reach in montane rain forest.

Many of the characteristics of the rain forest of the Rio León region are summarized in Table 2-3.

Table 2-3 uses Spanish colloquial names for the tree species encountered in the sample plots. These names were obtained from the local experienced native woodsmen associated with the work, and it was determined that they were being used consistently. The same name was always used for the same species, and the principal informant readily admitted that a specimen was "unknown" when it in fact was unknown to him.

The problem remains of botanical identification of the species and the attachment of correct classical scientific names. To this end materials needed for identification were collected whenever possible for nearly all of the species. Twigs with mature leaves and wood specimens with bark were collected for all species on the sample plots. Flowers and fruits were collected when available, but most specimens were in a vegetative condition at the time the field work was being done. This is unfortunate for it makes identification slow, tedious, and in some cases, speculative.

Arrangements have been made to send the wood samples and foliage specimens to specialists on tropical plants. This requires time and it is anticipated that the identifications will be published by Prof. Cain in technical journals at some future date.

TABLE 2-3

SOME TREE CHARACTERISTICS TYPICAL OF THE RAIN FOREST FORMATION RIO LEÓN, ANTIOQUIA, COLOMBIA

Trees with plank buttresses (11 species)

Some trees moderately planked - Nuanamo
Moderately planked - Cucharo, Guazimo, Majagua
Many planks - Rrobie
Large planks - Caracho, Bonga-agua
Planks broad and tall - Abrojo, Bonga, Manguito, Algo-don-zillo

Trees with fluted stems (6 species)

Sometimes fluted - Nuanamo
Somewhat flūted - Mangle-duro, Paleto, Guazimo, Ziete-cuero
Strongly fluted - Costillo

Strangler (1 species)

Cope, sometimes seated 50 ft or more high on another tree)

Trees with stilt roots (2 species)

Large stilts - Azeite
Many small roots with spines - Baceta

Trees deciduous in January (6 species)

Armazigo, Bambuo, Bonga, Bonga-agua, Caracho, Masagua

Trees with cauliflory (none seen)
Lianas (Many species reaching highest levels; stems to 6-8 in. dia.)
Epiphytes (abundant in middle and upper layers)
Leaves or leaflets entire

All species except Algo-don-zillo

Leaves simple, opposite (5 species)

Azeite, Cafe, Churunbelo, Laurel, Marro

Leaves simple, alternate (25 species)

Abrojo, Algo-don-zillo, Bole-nillo, Canilla-benao, Caracoli, Carbonero, Cocuelo, Costillo, Guazimo, Laure-ediondo, Lechozo, Lla-lla, Lla-lla-fruta-pava, Lla-lla-muetarisa, Menbrillo, Moroguei, Nispero, Nuanamo, Olleto, Paco, Plaeto, Zienegero, Unknown #1, #3, #4

TABLE 2-3 (CONT.)

Leaves pinnate, opposite (1 species)

Unknown #2

Leaves pinnate, alternate (19 species)

Baceta, Cedro-macho, Chagara, Chagara-cacao, Choiba, Cotibo, Cucharo, Curez-ta-gallo, Frijol, Fruta-zabalo, Guama-macho, Guere, Guino, Manguito, Ovo, Unknown #5, Wamon-de-mico, Ziete-cuero

Leaves otherwise: Palmate - Bonga, Bonga-agua, Cacaguillo, Mapurito,

Rroble; bipinnate - Dormilon; bifoliate - Mangle-duro; 3-lobed Camajon.

SECTION 3

STRUCTURAL FEATURES OF THE FOREST

Several features are important in the structure of vegetation, such as life form, stature, number, density, coverage and pattern of occurrence. To some extent each characteristic needs separate consideration in a description of the structure of a particular kind of vegetation, but in some cases certain features can be combined in tabular and graphic presentation.

Vegetation types are usually so complex and heterogeneous that any description other than a rhetorical one requires the use of some method of sampling, as the whole cannot be comprehended. This is especially true for quantitative data. When time permits and an investigation justifies it, sampling can be done in such a way and extensively enough that general statements about the whole can be made that are valid. Provided that the samples are typical of the area, they can suggest the nature of the vegetation. Two transects were laid out near the León test site. Data from these two samples are presented in scale diagrams which express some of the structural features of the forest around the test site.

3.1 DESCRIPTION OF THE TRANSECT AND PROFILE DIAGRAMS

Transect 1 was taken to the east of the instrumentation line and Transect 2 was taken to the west of it. Each one was far enough removed from the line not to have any effect on the meteorological data.

The procedure was as follows: a compass line was marked by a cord. Along the line a series of contiguous quadrats was measured that were 33 ft square (this is 2 rods or 1/2 chain on a side). The first transect was 10 units long, or 33 x 330 ft. The second transect was 12 quadrats long, or 33 x 396 ft. Working a quadrat at a time, each tree with 4 in. d. b. h. or more was located in the quadrat by measuring right-angle coordinates, i. e., diatance along the center line and distance at right angles to it. The location of each tree was recorded on coordinate paper to construct a flat map or plan as the work progressed.

Each tree was identified by a number placed on a blaze on the trunk. After the series was completed, the smaller trees were chopped down and additional measurements were made. In general, trees up to about 12 to 14 in. d. b. h. were cut down, and the larger trees were left standing. In some cases this provided enough clearing so that the larger trees could be seen and their heights measured by triangulation. When necessary, other trees were cut so that a clear sight could be obtained of the top of the center of the crown on each tree. For all of the larger trees the height to the first branch also was recorded, i. c., the clear bole length.

For the trees of these two sample plots the following data were obtained: (1) location on the transect, (2) d. b. h., (3) total height to the center of the crown, (4) height to the first branch, on larger trees, and (5) breadth and depth of the crown, or the foliage-bearing branches. Names were recorded in colloquial Spanish. Collections of twigs, foliage, wood, and bark were made for each species for later identification.

It is common for tropical trees to have swollen bases, stilt roots, plank buttresses and other features that pose a special problem of measurement. Because d. b. h. is a standardized measurement from which basal area is determined, it must not include any of those anomalies that would exaggerate the cross-section area at 4 1/2 ft above the ground. When such a problem occurred, the measurement was made above the butt swell, or the true d. b. h. was determined by projecting downward the side lines of the normal trunk. As normal measurements are made with a tree caliper for smaller trees and with a diameter tape for large ones, it was necessary in special cases to get the diameter by a straight-line measurement between the handles of two machettes held in line with the trunk sides, as described above. Diameter measurements, then, are believed to be accurate to the nearest inch. Height measurements were taken to the nearest foot. For tall, unfelled trees the true height may be as much as 5 percent more or less than the triangulated determination because of the difficulty of seeing the top of the center of the crown when viewed from the ground at distances 150 ft or more from the base of the tree. Height to the first branch is generally an accurate measurement, but total width and depth of the crown or foliage-bearing branches is based on estimates to the nearest 5 ft, for the largest trees. The profile data for Transects 1 and 2 are given in Tables 3-1 and 3-2.

The above data for trees are also presented by a new method of coordinate diagrams: (1) the flat map or plan of the transect, and

TABLE 3-1

PROFILE DATA FOR TRANSECT NO. 1, LEÓN SITE

No.	Species	D. B. H. (inches)	Height (feet)	Crown width & height (feet)
1	Nuanamo	7	55	20 x 15
2	Cucharo	4	40	15 x 20
3	dead			
4	Guino	7	66	22 x 30
5	Nuanamo	12	80	30 x 32
6	Cotibo	4	32	15 x 12
7	Nuanamo	6	56	12 x 21
8	Cotibo	12	92	40 x 30
9	Caracoli	69	149	70 x 30
10	Cotibo	4	27	15 x 20
11	Guino	10	88	30 x 48
12	Nauamo	12	108	20 x 15
13	Cotibo	11	98	25 x 30
14	Chagara	4	39	13 x 18
15	Cedro-macho	6	55	22 x 8
16	Cotibo	28	120	40 x 30
17	Cotibo	40	131	35 x 35
18	Gagua-macho	4	26	18 x 10
19	Lla-lla	6	55	18 x 25
20	Caracoli	53	93	25 x 15
21	Curez-ta-gallo	4	32	30 x 15
22	Moro-guei	4	50	14 x 20
23	Nuanamo	6	50	12 x 12
24	Mangle-duro	6	53	35 x 38
25	Lla-lla-fruta-pav	4	40	18 x 15
26	Mangle-duro	4	42	28 x 27
27	Curez-ta-gallo	4	28	25 x 16
28	Azcite	5	53	18 x 13
29	Cucharo	4	41	14 x 16
30	Cotibo	40	142	40 x 37
31	Paloto	14	78	32 x 20
32	Nuanamo	5	49	22 x 18
33	dead			
34	Olleto	42	149	45 x 30
35	Gagua-macho	5	36	16 x 16
36	Cotibo	11	83	40 x 28
37	Zienegero	4	35	8 x 10
38	Cotibo	4	31	15 x 12
39	Ziete-cuero	14	87	35 x 22
40	Guino	4	23	8 x 10
41	Guino	13	65	32 x 25
42	Cotibo	40	147	43 x 30
43	Carbonero	7	51	24 x 18
44	Dormilon	4	59	14 x 30
45	Nuanamo	8	61	13 x 20
46	Guino	12	83	35 x 15
47	Azeite	5	47	22 x 15
48	Nuanamo	4	35	10 x 15
49	Olleto	62	127	55 x 35
50	Guino	10	79	30 x 30
51	Azcite	4	39	24 x 13
52	Guazimo	6	61	30 x 18
53	Cotibo	25	102	55 x 35
54	Caracoli	74	129	80 x 60
55	Cotibo	10	57	12 x 6

TABLE 3-2

PROFILE DATA FOR TRANSECT No. 2, LEÓN SITE

No.	Species	D. B. H. (Inches)	Height (feet)	Crown width & height (feet)
1	Cotibo	33	105	50 x 30
2	Guere	8	67	25 x 15
3	Cotibo	4	31	12 x 10
4	Mangle-duro	7	63	20 x 35
5	Nuanamo	4	33	20 x 8
6	Guere	8	60	35 x 20
7	unknown	6	48	10 x 10
8	Ziete-cuero	7	53	20 x 15
9	Mangle-duro	11	76	30 x 25
10	Cotibo	4	34	14 x 8
11	Nuanamo	7	44	14 x 9
12	Fruta-zabalo	5	37	16 x 15
13	Cotibo	37	145	45 x 40
14	Cotibo	24	125	40 x 30
15	Olleto	87	156	80 x 56
16	Guino	4	41	24 x 10
17	Cotibo	39	146	50 x 30
18	Cotibo	4	31	18 x 14
19	Ziete-cuero	4	18	6 x 5
20	Guino	7	65	16 x 10
21	Mangle-duro	4	41	15 x 22
22	Cotibo	7	56	24 x 28
23	Dormilon	4	43	10 x 20
24	Cotibo	18	126	35 x 25
25	Laurel	4	50	20 x 25
26	Guazimo	30	90	40 x 25
27	Cotibo	17	115	30 x 30
28	Olleto	4	33	19 x 10
29	Guino	4	41	6 x 15
30	Caracoli	54	123	55 x 30
31	Guino	8	57	35 x 18
32	Guere	5	36	20 x 8
33	Nuanamo	8	50	10 x 16
34	Nuanamo	4	42	16 x 11
35	Nuanamo	5	40	18 x 14
36	Cucharo	13	116	40 x 30
37	Cope	8	120	
	This is a strangler, with milky juice, seated at 50' height on tree #36.			
38	Unknown	4	52	20 x 30
39	Mangle-duro	7	69	25 x 35
40	Lla-lla-muetarisa	7	69	35 x 20
31	Cotibo	12	93	22 x 33
42	Guino	4	24	10 x 15
43	Cruez-ta-gallo	5	41	6 x 20
44	Mangle-duro	5	31	14 x 18
45	Unknown	4	32	16 x 16
46	Manguito	7	53	6 x 20
47	Lla-lla-muctarisa	5	65	18 x 25
48	Guama-macho	17	128	55 x 40
49	Lla-lla	4	40	18 x 12
50	Guino	4	46	12 x 20
51	Carbonero	4	36	14 x 12
52	Bole-nillo	7	100	14 x 25
53	Caracoli	42	122	70 x 30
54	Nuanamo	7	55	20 x 20
55	Lla-lla	4	45	15 x 30
56	Cucharo	5	50	20 x 15
57	Chagara	11	85	35 x 20
58	Ziete-cuero	13	70	35 x 20

(2) the corresponding profile. The diagrams from Transects 1 and 2 are shown in Figures 3-1 and 3-2. On the plan each tree is shown as a black circle approximately to the scale of the corresponding diameter of the trunk at 4 1/2 ft above the ground, excluding anomalies. The numbers used to identify the trees are the same as those used in Tables 3-1 and 3-2. The crown spread is shown as a circle. The many branches do not, of course, form a circle, and the foliage does not form a continuous cover within the circle. The very large number of individual leaves or leaflets form a total leaf area many times the area of the diagramed circle, and although there may be many leaves one above another in any vertical line, there also are open spaces through which direct light and reflected light can penetrate. Finally, the plan is diagramed with solid lines for the uppermost tree crowns and broken lines for those part-crowns or whole-crowns that have other crowns above them. The canopy formed by trees standing outside the transect is cross-hatched. The diagram, then, suggests the view from above the forest looking directly down on it. One feature was seen from the air that is not apparent from the ground. The crowns of individual tall trees do not interpenetrate horizontally. Usually the edges of crowns of contiguous trees may nearly but do not quite meet.

The profile shows the trees of the transect as seen at right angles to the transect. Middle layer and lower trees are simply diagramed to scale to show d. b. h., total height, crown spread and depth as simple geometric figures. The trees of the upper stratum are drawn somewhat more authentically. Height of the first branch is shown. Branches correspond in a general way to field sketches, but they are not strictly representative.

Buttresses and occasional stilt-roots are not diagramed. The rather abundant lianas and the very abundant epiphytes are not shown in the diagrams. Trees smaller than 4 in. d. b. h. are not shown. They usually are rather numerous.

3.2 INTERPRETATION OF THE PLAN AND PROFILE DIAGRAMS

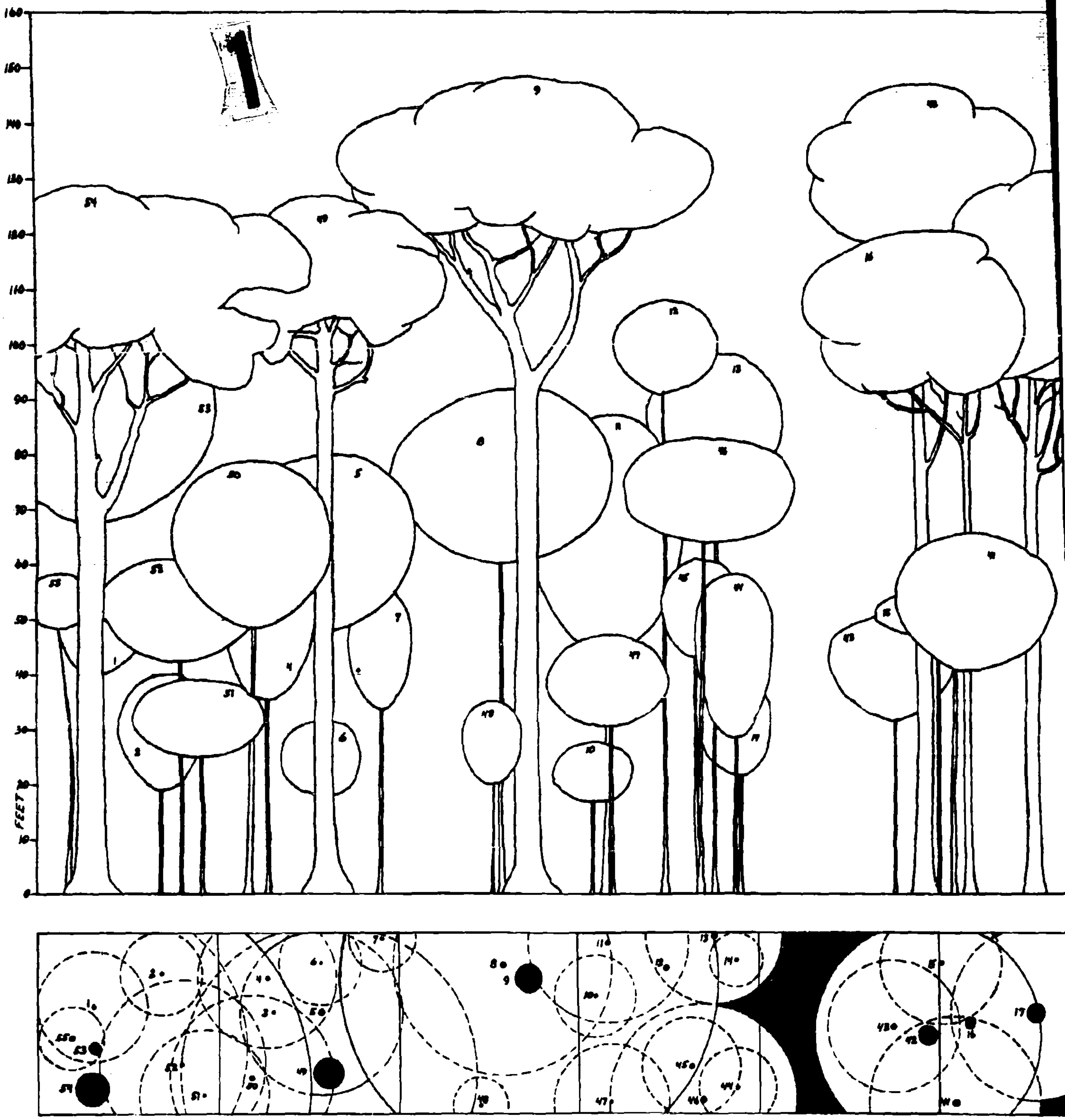
The forest is a tall one, the outstanding trees being 150 to 160 ft tall. The top of the forest is rather uneven. The tallest trees may occur singly, but more often as a group of a few trees separated by a more continuous layer of trees of maximum height of about 120 to 130 feet. The outstanding trees are not true "emergents." This term is best reserved for occasional rain forest trees which lift their entire crowns above the

level of surrounding trees. This penomenon is common in upland rain forest, but does not typically occur, if at all, in this floodplain rain forest. The result of the condition just described for the forest around the León site is that the top of the canopy has a rolling surface, tufted somewhat like deep heavy upholstery. The species of the outstanding trees (caracoli, olleto, cotibo) are also characteristic of the principal canopy with tops at 120 to 130 feet. Limited observation, however, suggests that there are several species in that canopy that never reach the maximum observed heights of 150 to 160 ft.

The profile diagrams suggest an intermediate layer with ceiling around 70 to 80 ft, and a lower layer around 40 ft.

Evident layers, however, are not characteristic of rain forest, certainly not of the stand under description here. There are two reasons: (1) this is a mature forest that is all-aged. The leading species of the forest occur at all heights, except for the tallest levels. That means that there are "transgressives," or trees destined for great height that are passing through the lower layers, obscuring their boundaries. (2) There are few or no species of innately limited mature heights that are numerous enough to present a visual layer. Dominance by one or a few species is generally not typical of the rain forest. However, there is a numerical and volume "predominance" by a few species in this forest that distinguishes it from typical upland rain forest. That dominance occurs only in the superior stratum. It is probably due to the floodplain site where the watertable is near or above the ground surface for perhaps two-thirds of the year or more.

As mentioned earlier, the irregular hatched areas in the plan diagrams show ground with no canopy above it resulting from trees within the transect. Such areas most likely are not open sky but are shaded by trees to one side or another of the transect, of which no account was taken on the narrow strip. When the forest was observed from the air, it was seen that it is possible in places to look into lower vegetation levels. For example, in spots one could look into openings and see the readily distinguished palms with ceilings 40 to 50 feet at the tallest, but actual ground was not visible. The overlapping tree crowns of the various levels present such a density of foliage cover that direct light reaches the ground only as diffuse light and occasional sun flecks. The intensity of light at ground level is estimated characteristically at only one or two percent of full light.



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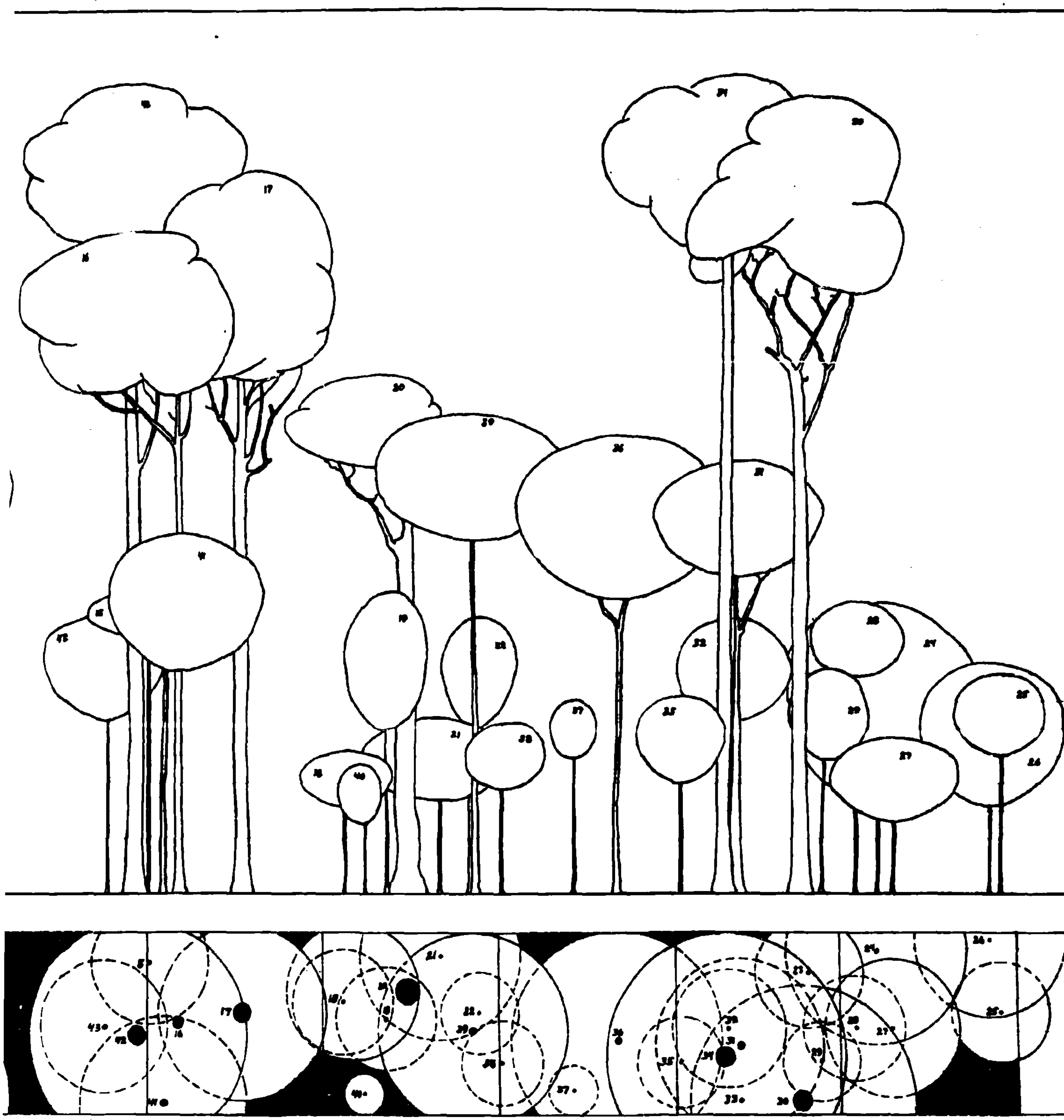
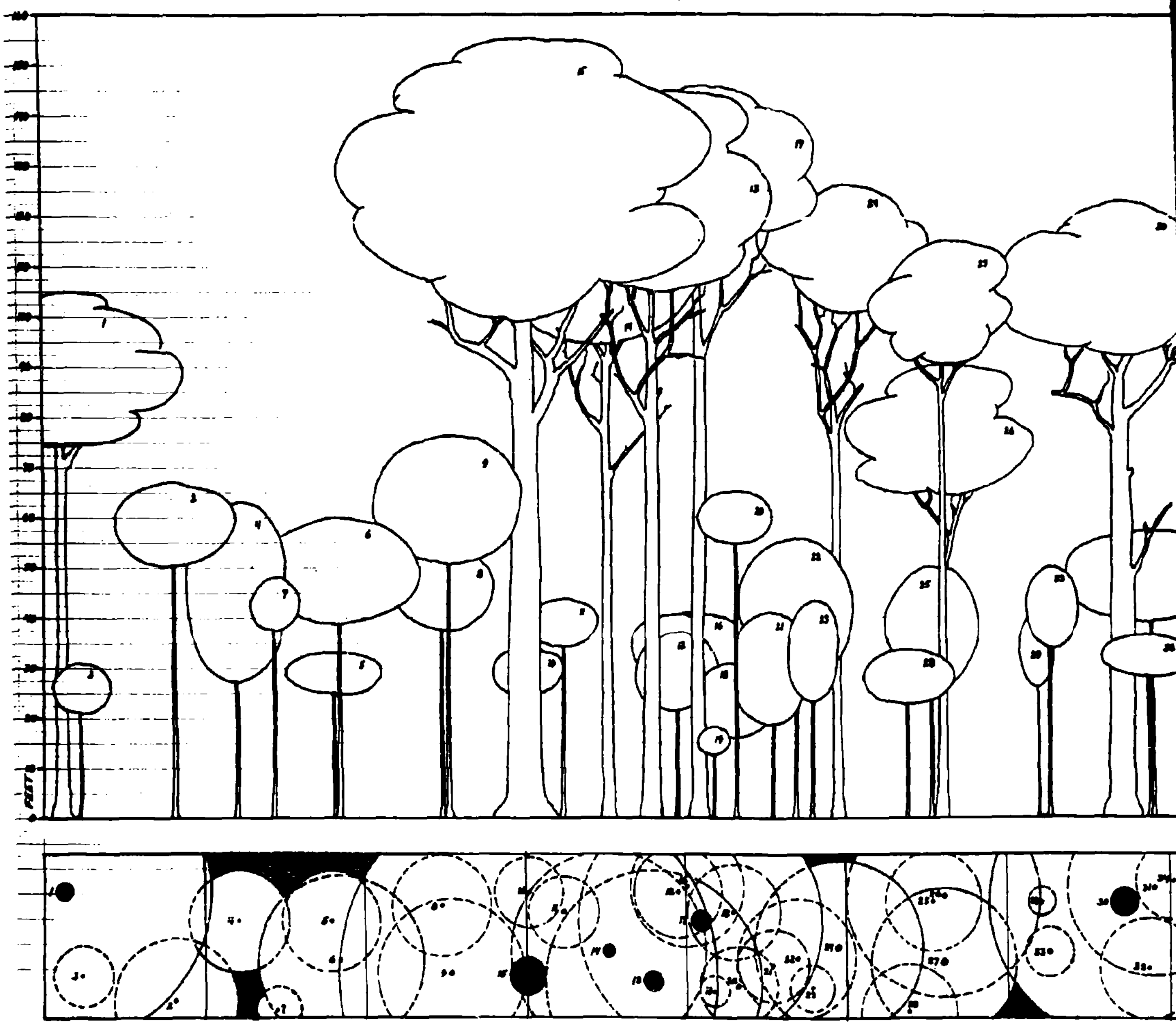


Figure 3-1 Plan and Profile Diagram of Transect 1, Leon Site



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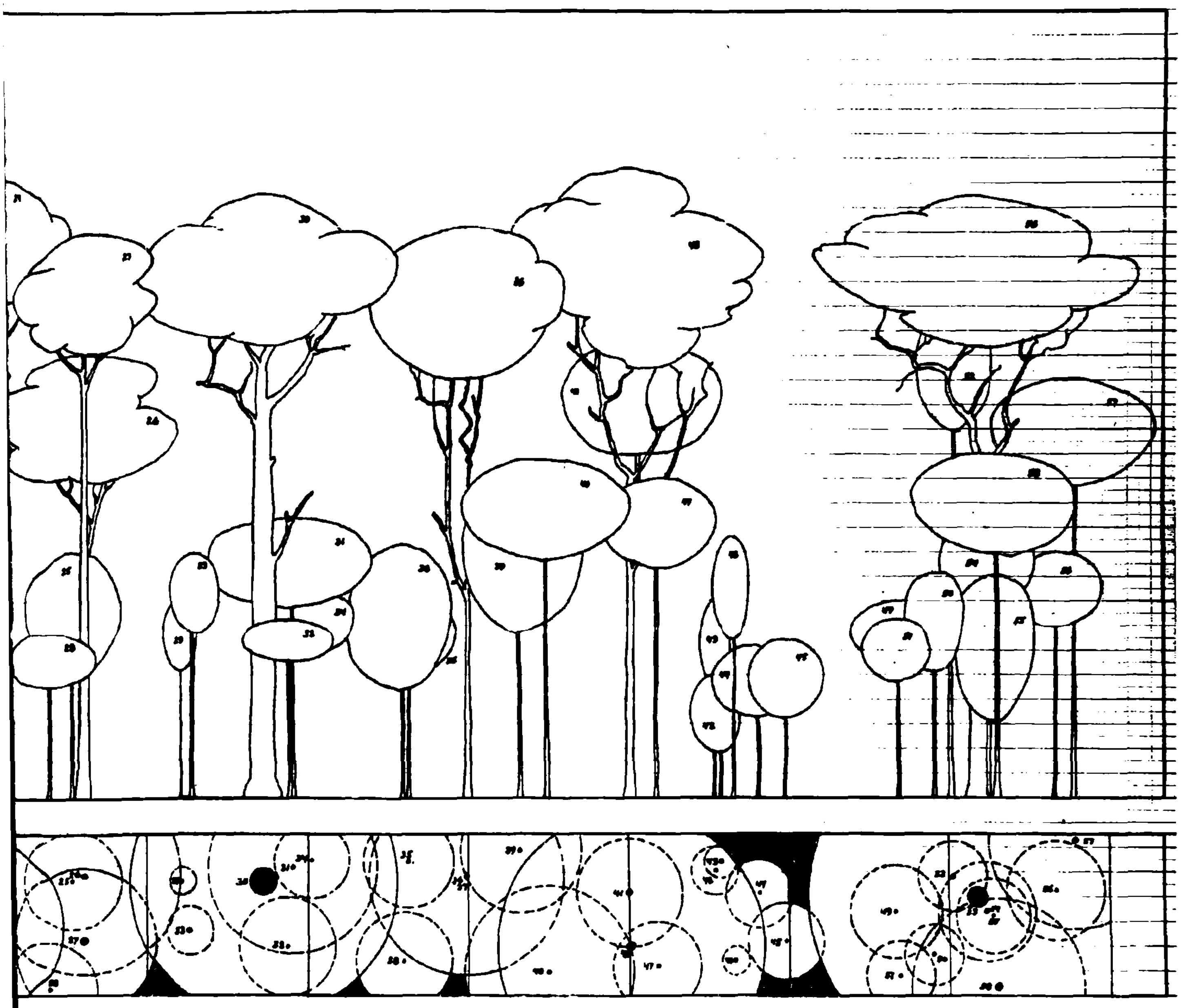

Figure 3-2 Plan and Profile Diagrams of Transect No. 2, León Site

The foliage appears to be densest at three levels, insofar as shown on the profiles, around 120 ft, 80 ft, and 40 ft. Because the small trees of 1, 2, and 3 in. d. b. h. are not shown, the profiles give a false impression of openness near the ground. In general, horizontal visibility is low from head height to 15 or 20 ft. The forest seems to be most open just below the canopy of the upper layer of trees and again just below the crowns of the middle layer of trees.

3.3 FOREST UNDERGROWTH

Because they are so numerous, smaller trees were excluded from the two plan and profile diagrams. These included only trees of 4-in. d. b. h. or more. In the vicinity of transect No. 1 two quadrats were laid out for the purpose of recording a sample of the undergrowth. On this plot, which was 33 x 66 ft, small trees of the 1, 2 and 3-in. d. b. h. classes were located and their heights measured. Crown width and depth were not recorded as it is clear from the abundance of the small trees that this lowest layer has dense foliage and an essentially continuous canopy. The results of this sample are shown in Figure 3-3. These trees numbered 72 on the plot or about 1440 per acre. They are shown on the plan as dots without numbers, and on the profile as vertical lines scaled to the height of each tree.

The accompanying photographs show the typical density of this layer. In Figure 3-4 only one large tree, a costillo with fluted trunk, is shown, and perhaps two dozen small trees are visible. Part of the foliage in this picture is that of a climbing fern seen over the man's right shoulder, but most of it belongs to the small trees. Figure 3-5 shows one large tree, a majagua with a few buttress planks, and numerous small trees. One of the trees in the center background is a spiny black palm; the tip of one leaf is at the top of the picture and there are others in the background.

Figure 3-5 also shows part of a patch of wild pineapple which has stiff spiny sword-like leaves up to 6 or 7 ft long. Other non-tree plants include slender-stemmed shrubs of the Melastomaceae and Piperaceae varieties and the somewhat fleshy stemmed Heliconia (Strelitziaceae), and occasional members of the Zingiberaceae, Cannaceae and Marantaceae. Only a very small number of herbaceous plants occurs under the dense shade of the forest. There is a rather frequently encountered sedge called cortadera (Cyperaceae), and occasionally a grass (Gramineae) that is probably an Olyra. Selaginella stellata (Selaginellaceae) is occasional

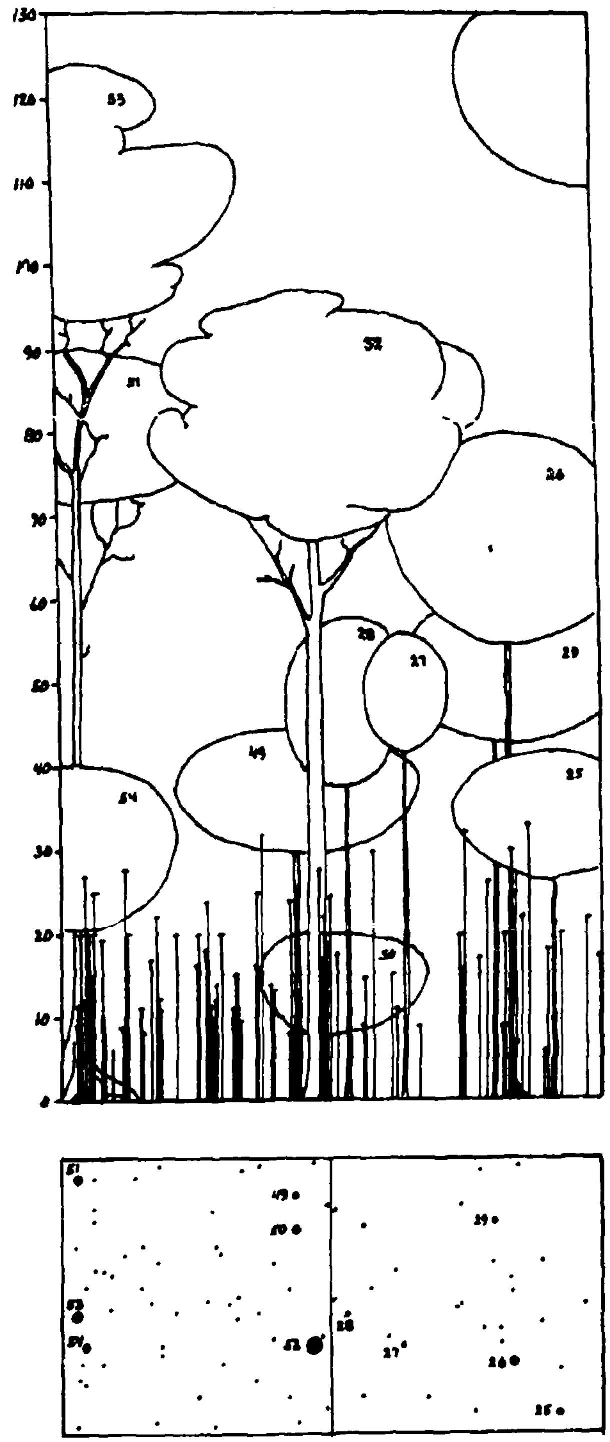

Figure 3-3 Plan and Profile of Undergrowth in Part of Transect 1, Leon Site
Only Trees With d. b. h. of 1, 2, 3 Inches Are Shown

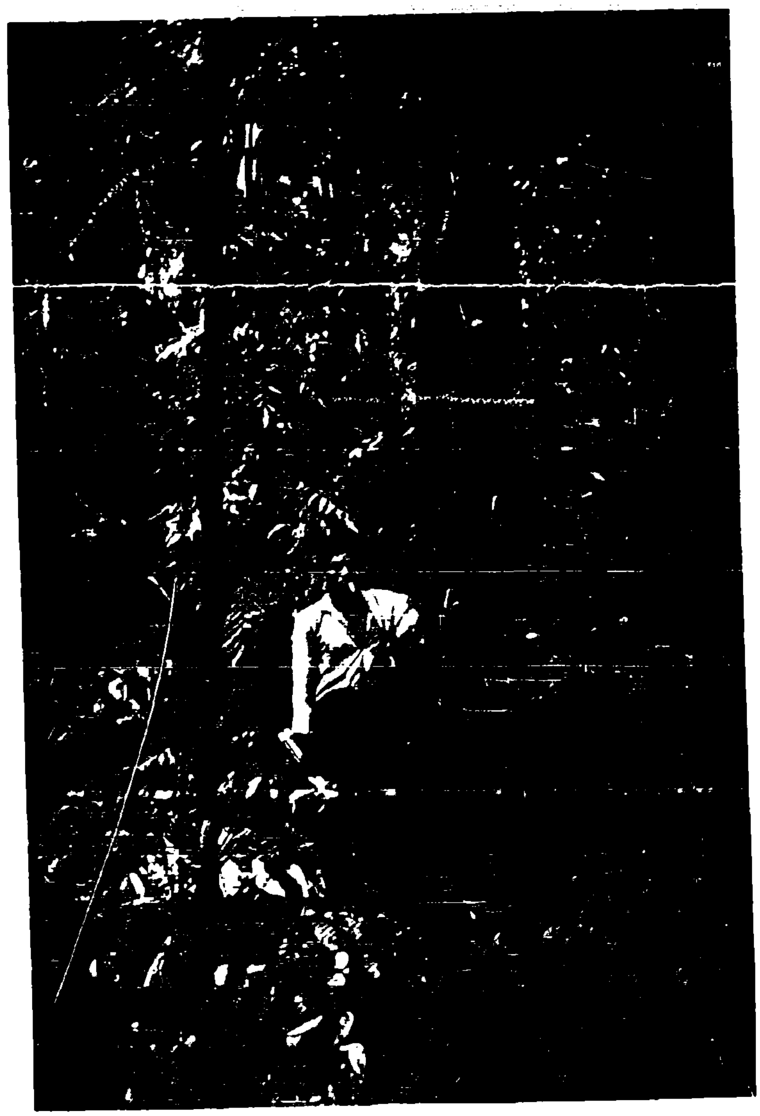

Figure 3-4 Typical Density of the Undergrowth Near the Test Site

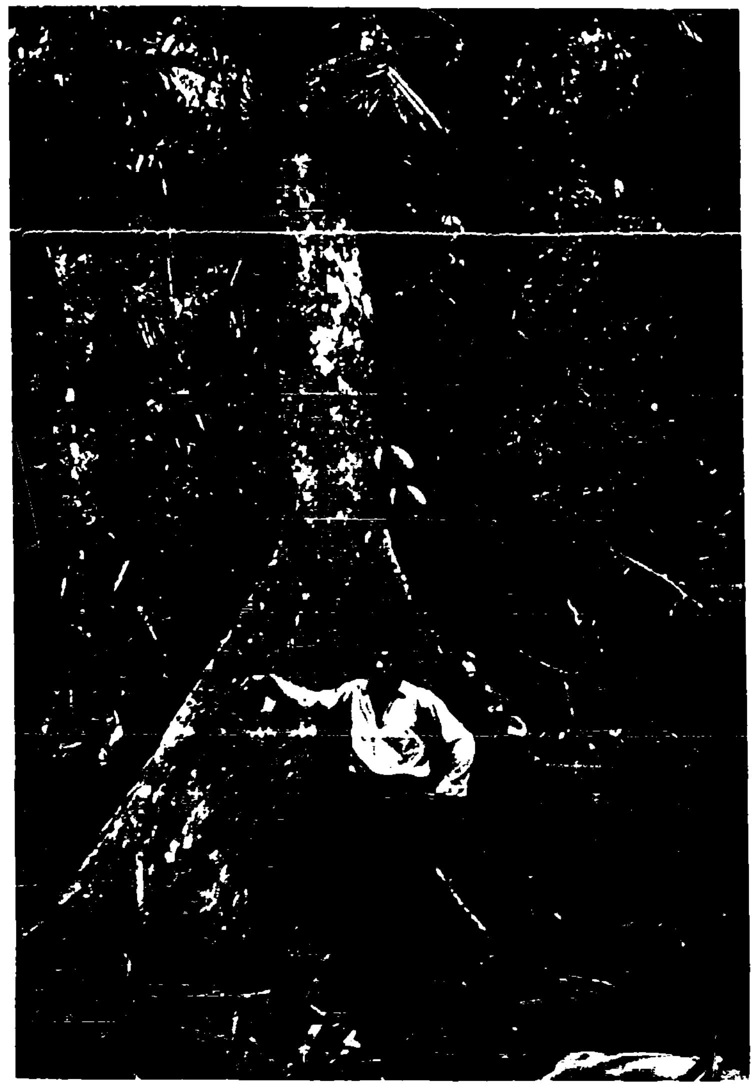

Figure 3-5 Example of Large Tree and Numerous Small Trees Typical of Area

and an herbaceous geophyte, referred to as zebolleta is locally common. However, in general both the shrub and herb layers are very sparse and most of the cover near the ground is made up of tree seedlings. The entire forest is predominatly phanerophytic, i.e., woody.

SECTION 4

STAND COMPOSITION

The first day in the woods was spent on a reconnaissance to gain a general impression of the forest. The route taken led from the camp on the river to the test line where each of the fourteen stations was looked at, and then on westward to the Rio Tumaradó. Figure 4-1 presents these landmarks, but the map, obtained from the engineer in Chigorodo, exaggerates the distance to the Tumaradó.

It became apparent that the forest was of a single heterogeneous type (a lower more swamp-like forest was seen from the air but is absent from the immediate vicinity of the test site). It also seemed that the forest was heavier, i.e., very large trees were more numerous, in the vicinity of the test line. On the return to camp a station was sought east of the test line that seemed typical of the forest in general. One was selected at the edge of an area where logs of cotibo were being removed. This became the location of transect 1 which was started the next day. After it had been completed, transect 2 was worked on at a site west of the instrumentation line. Further observation had suggested that variations in the forest would be better represented if the second transect had fewer large trees than occurred at either the test line or transect 1. So transect 2 tends to balance out the fragmentary sampling of the forest as a whole.

These are the transects which have already been discussed in Section 3. Although species have been identified in Tables 3-1 and 3-2, the primary purpose of the sampling was to indicate the physical features of the forest. The great amount of data collecting necessary to prepare the plan and profile diagrams in Section 3 limited the size of each transect. Quantitative data on stand composition were also collected and are reported in this section. For this purpose both transects 1 and 2 were extended in length to provide a larger and more reliable sample on which to base composition data.

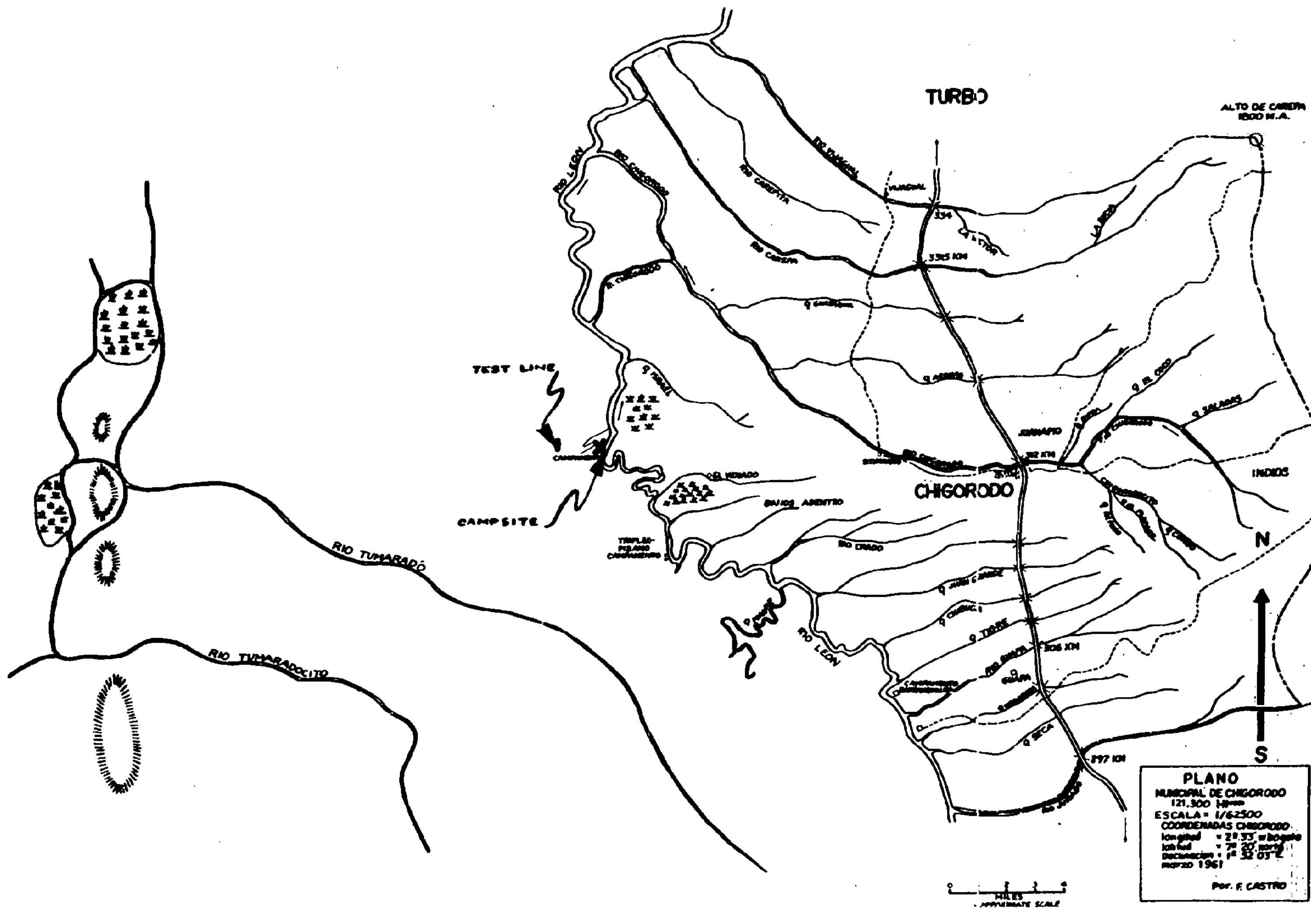

Figure 4-1 Detailed Map of Test Area

4.1 COMPOSITION OF TRANSECT 1

This transect was 12 units long (a unit is 33 x 33 ft). Table 4-1 shows the number of stems of each species and the aggregate basal area for each species present. Stem diameters were measured to the nearest inch for trees 4 in. or more in diameter at 4 1/2 ft above the ground (d.b.h.). Basal area is the circular cross-section area of the tree trunks at 4 1/2 ft above the ground. It is recorded in sq ft. The sample plot had a total basal area of 152.67 ft^2 on 0.3 acre for an average basal area of 508.9 ft^2/acre, and the three leading species made up 92.1 percent of the total for 22 species.

4.2 COMPOSITION OF TRANSECT 2

This transect was 20 units long and was developed in the same way as transect 1. On 0.5 acre the basal area was 112.31 ft^2 for an average basal area of 224.32 ft^2/acre, or less than half that of transect 1. The same three leading species made up 85.6 percent of the total basal area of 24 species. The results are summarized in Table 4-2.

4.3 COMPOSITION OF PLOTS OF THE TEST LINE

Procedure in examination of the 14 instrumentation stations of the 1100 meter, north-south test line was different from that for the transects in several ways. The north, middle and south stations were centered on the towers. The 11 other stations, including the two wing stations lying 200 m east and west of the middle tower, centered on large trees. The tree stations were selected so that a ladder could be fastened to the trunk and a boom attached to it at about 100 ft above the ground in order to expose rotorod samplers at selected heights. For reasons connected with the meteorological studies, every effort was made to minimize disturbance of the forest in the vicinity of the line, and especially near the instrumentation stations. Accordingly it was decided to make use of circular plots of 66 ft radius centered on the towers and the line trees rather than develop a strip transect centered on the line itself. It was also decided to measure and record only trees of 10 in. d.b.h. or larger, and not to locate them on the plots or determine their height. This prevented cutting of smaller trees and kept disturbance to a minimum.

Thirty different species in this size range were present in the aggregate 14 plots. Their identify, occurrence and basal areas are summarized in Table 4-3.

TABLE 4-1

COMPOSITION DATA FOR TRANSECT 1, LEÓN SITE. (TRANSECT AREA 33 x 396 FT TREES 4 IN. D.B.H. AND OVER)

Species	Number of Stems	Basal Area sq. ft.	% total B.A.
Caracoli	3	70.58	46.2
Cotibo	14	39.61	25.9
Olleto	2	30.59	20.0
Three leading species	19	140.78	92.1
Guino	8	3.72	
Nuanamo	11	1.90	
Paleto	1	1.07	
Ziete-cuero	1	1.07	
Guazimo	2	0.98	
Chagara	2	0.54	
Guere	2	0.46	
Azeite	3	0.28	
Mangle-duro	2	0.28	
Carbonero	1	0.27	
Gagua-macho	2	0.22	
Lla-lla	1	0.20	
Cedro-macho	1	0.20	
Cucharo	2	0.17	
Curez-ta-gallo	2	0.17	
Moro-guei	1	0.09	
Lla-lla-fruta-pava	1	0.09	
Zienegero	1	0.09	
Dormilon	1	0.09	
Total	64	152.67 ft^2/0.3 acre	
Per acre	213	508.9 ft^2	

TABLE 4-2

COMPOSITION DATA FOR TRANSECT 2, LEÓN SITE. (TRANSECT AREA 33 x 660 FT TREES 4 IN. D.B.H. AND OVER)

Species	Number of Stems	Basal Area sq. ft.	% total B.A.
Olleto	2	41.37	36.7
Cotibo	11	29.50	26.2
Caracoli	2	25.52	22.7
Three leading species	15	96.39	85.6
Guazimo	1	4.91	
Guama-macho	1	1.57	
Mangle-duro	5	1.42	
Ziete-cuero	3	1.27	
Nuanamo	6	1.19	
Cucharo	2	1.06	
Guino	6	0.97	
Guere	3	0.83	
Chagara	1	0.66	
Lla-lla-muetarisa	2	0.40	
Bole-nillo	1	0.27	
Manguito	1	0.27	
Unknown No 1	1	0.20	
Lla-lla	2	0.17	
Fruta-zabalo	1	0.14	
Curez-ta-gallo	1	0.14	
Dormilon	1	0.09	
Laurel	1	0.09	
Unknown No 2	1	0.09	
Unknown No 3	1	0.09	
Carbonero	1	0.09	
Total	57	112.31/0.5 acre	
Per acre	114	224.32 ft^2	

TABLE 4-3

COMPOSITION DATA, 14 LINE PLOTS, LEON SITE, (TREES 10 IN. D.B.H. AND OVER, F GIVES THE PERCENTAGE OF PLOTS CONTAINING THE GIVEN SPECIES)

Species	Number of Stems 10" d.b.h. and over														F		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Percent	No.	Basal Area
Nuanamo	5	3	1	.	.	1	.	.	.	.	1	.	1	.	42.9	12	12.39 ft^2
Cedro-macho	1	.	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	1.11
Abrojo	1	.	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	8.27
Manguito	1	.	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	6.93
Olleto	3	1	3	.	.	1	1	1	.	1	1	.	.	1	64.3	13	125.68
Bole-nillo	1	.	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	.79
Guino	2	6	3	2	1	1	1	1	4	.	.	.	3	.	71.4	24	55.15
Cotibo	.	1	3	3	7	3	8	8	6	5	8	4	9	8	92.8	73	455.27
Mangle-duro	.	1	.	2	4	2	3	9	1	3	4	7	3	2	85.7	41	70.58
Algo-don-zillo	.	1	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	3.14
Lechozo	.	1	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	1.40
Bongo	.	1	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	13.63
Bongo-agua	.	1	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	7.07
Azeite	.	1	1	.	.	2	.	.	.	1	.	.	.	.	28.6	5	4.48
Cucharo	.	1	.	.	1	2	.	.	.	.	1	2	1	1	50.0	9	10.72
Ovo	.	1	.	1	.	.	.	.	.	.	.	.	.	.	14.3	2	4.29
Caracho	.	1	.	.	.	.	.	.	.	.	.	.	.	.	7.1	1	7.88
Paleto	.	.	1	1	.	.	.	.	.	.	.	.	.	.	14.3	2	1.45
Caracoli	.	.	2	1	1	1	1	.	.	.	.	.	.	.	35.7	6	103.10
Ziete-cuero	.	.	.	2	2	.	.	.	.	.	.	.	.	.	14.3	4	2.76
Rroble	.	.	.	1	1	.	.	.	.	.	.	.	.	.	14.3	2	3.58
Dormilon	.	.	.	.	1	.	.	.	.	.	.	.	.	.	7.1	1	1.40
Choiba	.	.	.	.	1	.	.	.	.	.	.	.	1	.	14.3	2	9.47
Cocuelo	.	.	.	.	.	1	.	.	.	.	.	.	.	.	7.1	1	2.40
Unknown #1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	7.1	1	.92
Guazimo	.	.	.	.	.	.	.	.	3	.	.	2	.	.	14.3	5	10.25
Unknown #2	.	.	.	.	.	.	.	.	.	1	.	.	.	.	7.1	1	.54
Unknown #3	.	.	.	.	.	.	.	.	.	1	.	.	.	.	7.1	1	1.40
Carbonero	.	.	.	.	.	.	.	.	.	1	.	.	.	.	7.1	1	.79
Frijol	.	.	.	.	.	.	.	.	.	.	.	.	1	1	14.3	2	1.32
Species/plot	7	13	7	8	9	9	5	5	4	7	5	4	7	5	(Average = 6.8		
Stems/plot	14	20	14	13	19	14	14	20	14	13	15	15	19	13	(Average = 15.5)		

Basal area: Total = 928.16 ft^2,

per plot average = 66.3 ft^2, range = 40.21 to 97.01 ft^2

Total area of 14 circular plots = 1.4 acres

The resulting data on basal area contain certain sources of error. The data do not compare on an areal basis with the transects because trees of the 4- to 9-in. diameter classes were omitted. However, these smaller trees do not make up much of the total basal area of a plot when even one very large tree is present. In addition, the basal area of 11 of the plots which are centered on large trees will tend to run greater than normal because of the fact that each plot starts with one large tree. The forest stand at the test line is exceptionally heavy, with numerous large trees, and tends toward one extreme for the forest as a whole. However, it would not have been possible to have selected a truly average site for the instrumentation line without a very extensive preliminary survey of the forest of the region.

Because the 14 circular line plots were separate rather than contiguous, like the square plots of the transects, it was interesting to record separately the presence or absence from an individual plot of trees of each species encountered. These data are given as number of stems present for each species in each plot, and they permit calculation of frequency for each species. In this sense, "frequency" is the percentage of the total plots of a set of plots in which a given species is present. It is not a function of the total number of stems of the species.

4.4 COMPARISON OF THE THREE SAMPLES

Table 4-4 compares the data from transects 1 and 2 and from the line plots for several species as to total basal area and number of stems. The species are grouped as follows: Those referred to as being in the superior stratum (cotibo, olleto, caracoli) are not only dominant in the highest layer but also are the only species observed to rise above its general level to the maximum heights of the forest. The transition trees (mangle-duro, guino) are those that have their tallest members in the lower part of the superior stratum, do not reach heights of 150 to 160 feet and are more numerous in the second lower stratum. The species of the intermediate stratum (nuanamo, guazimo) were not tall enough to enter the superior stratum at all.

Further examination of the data from all sample plots shows that three species (cotibo, olleto, caracoli) provide an actual dominance, as measured by basal area, in the forest as a whole. This is especially true of the superior stratum. Together they make up 73.6 percent of the total basal area of the line plots, 85.7 percent of it on transect 2, and 92.1 percent of it on transect 1. Even among these dominants the heterogeneity

TABLE 4-4

COMPOSITION COMPARISON OF LEADING SPECIES OF TREES ON SAMPLE PLOTS, LEÓN SITE. (BASAL AREA AND NUMBER OF STEMS IN PERCENT OF TOTAL IN SAMPLE)

	Test Line plots	Transect 1	Transect 2
Area sampled	1.4 acres	0.3 acres	0.5 acres
Total species sampled	30	22	24
Superior stratum			
Cotibo			
Basal area	49.0	25.9	26.3
Number of stems	33.6	21.9	19.3
Olleto			
Basal area	13.5	20.0	36.7
Number of stems	6.0	3.1	3.5
Caracoli			
Basal area	11.1	46.2	22.7
Number of stems	2.8	4.7	2.5
Total for stratum			
Basal area	73.6	92.1	85.7
Number of stems	42.4	29.7	27.3
Transition			
Mangle-duro			
Basal area	7.6	0.2	1.3
Number of stems	18.9	3.1	8.8
Guino			
Basal area	5.9	2.4	0.9
Number of stems	11.1	12.5	10.5
Total			
Basal area	13.5	2.6	2.2
Number of stems	30.0	15.6	19.3
Intermediate stratum			
Nuanamo			
Basal area	1.3	1.2	1.1
Number of stems	5.5	17.2	10.5
Guazimo			
Basal area	1.1	0.7	4.4
Number of stems	2.3	3.1	3.5
Total for stratum			
Basal area	2.4	1.9	5.5
Number of stems	7.8	20.3	14.0
All other species			
Basal area	10.5	3.4	6.6
Number of stems	19.8	34.4	40.4

is shown where cotibo makes up 49 percent of the total basal area of the line plots and drops to about a quarter of it on the transects, while caracoli rises to 46.2 percent of the basal area on transect 1, and olleto to 36.7 percent on transect 2.

Mangle-duro, which is a relatively important species of the intermediate stratum and the transition between it and the superior stratum, has 41 stems 10 in. d.b.h. or more on the line plots and 70.58 sq ft of basal area. Again the heterogeneity is apparent in its moderate occurrence on transect 2 and its slight role on transect 1. Guino is rather similar in its occurrence. Most other species are scattered and enter the statistics in a minor way. Still, those species which are only occasional can appear to be relatively important in the forest when even a single large specimen is encountered in the sampling. Illustrations of this point selected from the line plots include abrojo, manguito, bongo, bongo-agua, caracho, and choiba, for which single stems tend to produce around 7 to 8 sq ft of basal area.

SECTION 5

CONCLUSIONS

1. The test site lies within the humid tropics as defined by Garnier and Küchler [1].

2. The forest at the test site is a true rain forest. It is a tall one with an undulating surface comprised of outstanding trees in groups reaching 150 to 160 ft and a principal canopy at 120 to 130 ft. Twenty-one species were observed to exceed 100 ft. Quantitative data suggest an intermediate layer around 70 to 80 ft and a lower layer around 40 ft, but layers are not readily evident in this stand.

3. By observation from the air, through openings one can occasionally see down to palms at 40 to 50 ft, but actual ground is not visible.

4. Daylight reaches the ground only as diffuse light and occasional sun flecks. The intensity of light is estimated at 1 to 2 percent of full light.

5. Stand composition was determined for two rectangular transects and for fourteen circular plots. The principal results of this determination appear in Table 5-1 below.

TABLE 5-1

PRINCIPAL RESULTS OF STAND COMPOSITION IN SAMPLE TRANSECTS AND PLOTS AT LEÓN SITE

Location	Size of Trees Surveyed	No. of Species	No. of Stems/Acre	Basal Area in ft^2/Acre
Transect 1	≧4 in. d.b.h.	22	213	509
Transect 2	≧4 in. d.b.h.	24	114	224
14 Circular Plots	≧10 in. d.b.h.	30	155	662

6. Three species, cotibo, olleto, and caracoli provide an actual dominance as measured by basal area (>75 percent) and together comprise the upper strata.

SECTION 6

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VOLUME II

PART II

METEOROLOGY OF THE RIO LEÓN TEST AREA

An analysis of the meteorological data
collected during the project.

PART II

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SECTION 1

INTRODUCTION

The foregoing description of the forest emphasizes the physical features which induce a microclimate, distinct from the general macroclimate. The resulting microclimate is documented in the following sections.* Some macroclimatological data were also collected and these and the observed microclimate are discussed against the background of existing data.

Relatively few climatological data are available for the region of Colombia containing the test area. There were enough, however, to establish the broad lines, to indicate that this is a region of tropical rain forest, that there is a 3 to 4 month dry season, that relatively steady northerly trades feature the dry season. This kind of macroclimatological data is presented below. Next follows an analysis of the data gathered by this expedition, under separate subject headings, according to the meteorological element. The discussion closes with an account of a special 72-hour run which was carried out in late April as the dry season was coming to an end. The 72-hour study serves to illuminate much of what is described in earlier sections and provides the last word on temperature and humidity in this region.

The test area is located in a broad flat valley that is drained primarily by the Rio Atrato, although the Rio León also flows directly into the Gulf of Uraba. The main geographic features and site of the test area are shown in Figure 1-1. The proximity to the equator and to both the Pacific Ocean and Caribbean Sea may be noted.

Climatological data for Turbo are available in a U. S. Hydrographic Office publication.[1] These data are reproduced in Tables 1-1 and 1-2. Isotherms for this region, as given by Lauer[2], show that temperatures average about 80°F for the year. Month to month changes are minor, but slightly cooler temperatures occur during January, February, and March when the northerly trades blow with great regularity.

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*Meteorological instrumentation in the test area was designed and installed by the Meteorological Laboratory of The University of Michigan under the direction of Professor Gerald C. Gill.

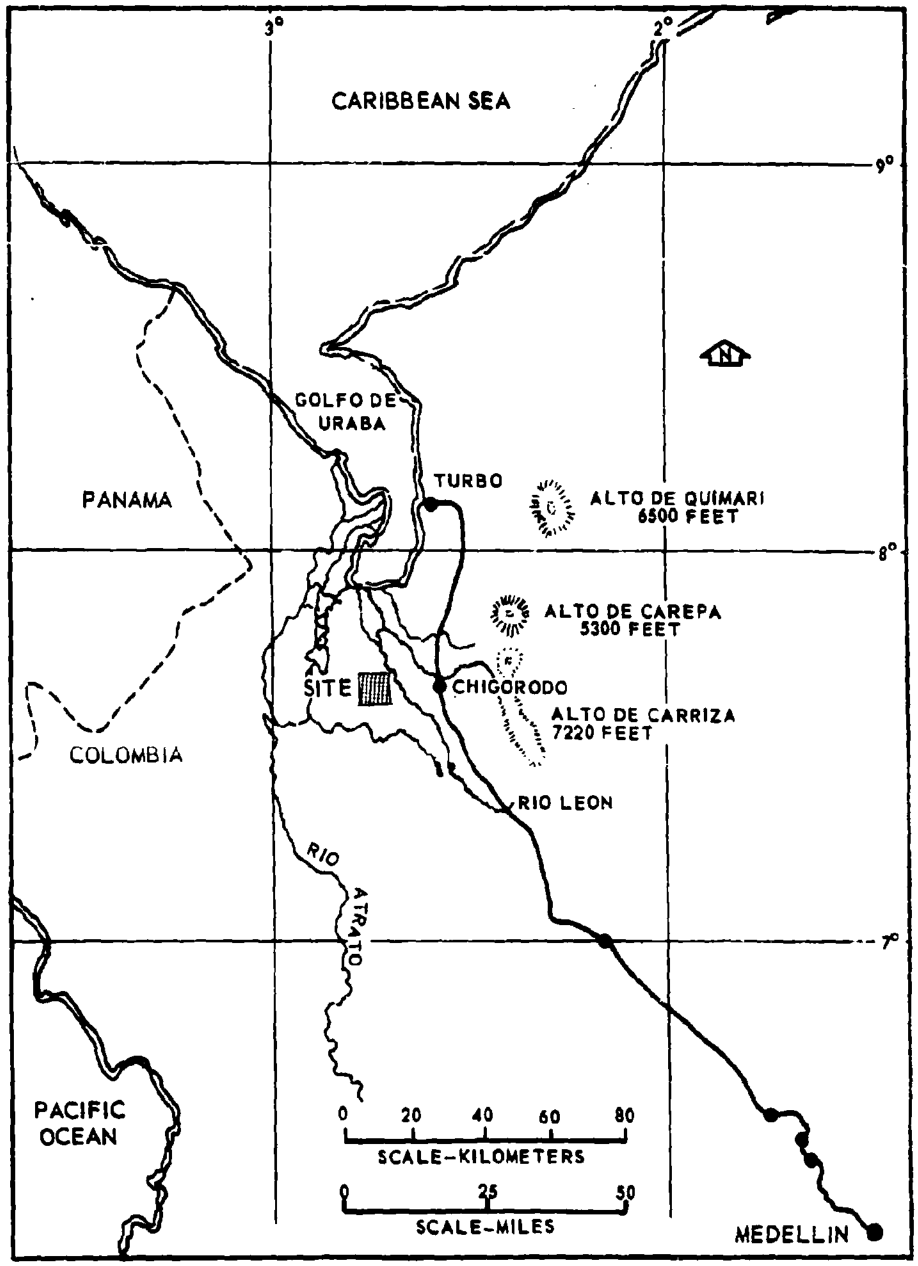


Figure 1-1 Site for Jungle Canopy Penetration Study Chigorodo, Columbia

TABLE 1-1

SOME CLIMATOLOGICAL ELEMENTS FOR TURBO, COLOMBIA, BY MONTHS

Month	RAINFALL			WIND		
	Avg. Amt	No. of Rainy* Days	No. of Days With Thunder	Mean Speed	Prev Dir	No. of Days With Gales
Jan	3.0 in.	4	0.8	7.4 kts	NNW	3.4
Feb	2.5	4	0	9.1	NNW	8.2
Mar	1.3	5	1.0	7.8	N	7.8
Apr	5.6	7	0.5	7.0	NNW	4.4
May	11.5	16	3.3	5.6	SW	2.2
June	11.1	15	3.8	7.4	SSW	1.2
July	12.9	14	5.5	5.6	SSW	1.2
Aug	11.7	13	2.5	6.1	SSW	3.2
Sept	8.8	14	5.0	6.1	S	3.2
Oct	9.5	11	2.9	7.4	SW	4.3
Nov	13.1	15	2.1	5.2	S	2.7
Dec	10.7	12	1.5	9.1	NNW	1.6
Total	102	130	28.9			

*Rainy days are those with rainfall $\geq$ .01 inches

TABLE 1-2

RELATIVE FREQUENCY AND SPEED OF SELECTED WIND DIRECTIONS, BY SEASONS FOR TURBO, COLOMBIA

Season	NNW, N, NNE		SW, WSW, W		SSE, S, SSW	
	Rel Freq	Av Speed	Rel Freq	Av. Speed	Rel Freq	Av Speed
Winter	52.9%	11.6 kts	5.8%	12.9 kts	2.2%	6.5 kts
Spring	44.9	10.9	8.0	6.0	8.8	5.5
Summer	20.7	10.2	28.6	5.1	15.1	6.6
Fall	17.3	9.4	21.7	5.8	28.0	7.1

The most striking feature of Table 1-1 is the clear evidence of a dry season. This is shown in average monthly rainfall, in the distribution of days with rain, and in the distribution of days with thunder. Associated with this dry period are prevailing northerly winds off the Caribbean Sea. Table 1-2 is presented primarily to show the extent to which northerly winds are dominant on the average. The statistic "prevailing wind" is one of the least indicative of all weather statistics, since a wind direction need only be more frequent than the other fifteen directions to qualify as "prevailing". Here, however, there is clear-cut dominance by northerly winds in winter and spring. No comparable dominance from any sector occurs during summer and fall when the trade winds weaken

Table 1-1 also attests to the kind of rain that occurs in this region. It can be seen that the number of rainy days is far in excess of the number of days with thunder. Moreover the rainiest months are those with the lightest average wind speed. It may be inferred therefore, that in this region of the tropics rains usually occur without thunder. Moreover they are not accompanied by high winds as is the rule in temperate regions.

The acquisition of data began in late February of 1962 and extended into the latter half of April. Hence the data may be expected to show initially the characteristics of the dry season, with some evidence of a breakdown of this regime towards the end of the field program

SECTION 2

TEMPERATURES IN THE RAIN FOREST

The test area was a mile to the west of the Rio León in the heart of rain forest, with tree tops reaching nearly to 150 feet. Thermometers were mounted at eight levels on two 200-foot towers 1100 m apart as described in Sections 4 and 6 of Volume III of this report. The levels were as follows:

a - level	6.5 feet above ground
b	30
c	56
d	74
e	100
f	146
g	170
h	192

The vegetation report contained in Part I of this volume shows that the forest was most dense just above the e-level, that it was already quite open at the f-level, and that the g- and h-levels were completely above the canopy.

Temperatures were recorded on both towers during thirteen 10-hour trials; and on the north tower only during a special 72-hour run at the conclusion of the trials. The data collected during the 72 hours are discussed in Section 5. Temperatures were read at the beginning of each 30-minute sampling interval, and a mean of two consecutive values was logged as

representative of an interval. The good internal consistency of the data indicates that there would be little gain in accuracy from more frequent reading of the charts.

2.1 THE COURSE OF TEMPERATURE

Trials were conducted either during the 10 hours from 0700 to 1700 or from 1700 to 0300 EST. Thus there was an indication of the temperature trend for all except the 4 hours from 0300 to 0700. The course of temperature as observed at the north tower will be described. That this record is representative is shown in Section 2.2 by the exceptionally good agreement between the two towers.

Figures 2-1, 2-2, 2-3 and 2-4 depict the course of temperature at all eight levels on a clear day, a cloudy day, a clear night, and a cloudy night. Crossing over of the graphs for different levels has been avoided by spacing the temperature scales 1°C apart. The figures show that most temperature changes above the canopy, of even a few tenths of a degree, are accompanied by changes of only slightly lesser magnitude below the canopy. It might be concluded from the curves for trial 2 in Figure 2-1 that the maximum at 6.5 ft (the a-level) precedes that at 192 ft (the h-level), but this was not confirmed by the other three day trials.

The general trends that can be noted are entirely consistent with the 0600 sunrise and 1800 sunset. The 5 hours from 0700 to 1200 were characterized by rapidly rising temperatures at all levels, with a lower rate of rise on the cloudy day. The 5 hour period from 1200 to 1700 is featured by the daily maximum, occurring between initially rising and later falling temperatures. The 5 hours from 1700 to 2200 cover the first rapid fall in temperature associated with sunset and radiational cooling. The 5 hours from 2200 to 0300 show a much slower, but very uniform rate of temperature decrease. Dew formation is likely to be a factor in slowing the cooling rate after 2200. The division of the temperature records into these four 5-hour periods is continued in the following discussion in order to explore the influence of warming and cooling trends on the correlation between the two temperature facilities 1100 m apart in the forest.

2.2 TEMPERATURE COMPARISONS BETWEEN THE TWO TOWERS

Temperatures were being measured at eight levels on each of two towers located on a north-south line 1100 m apart. The two towers will

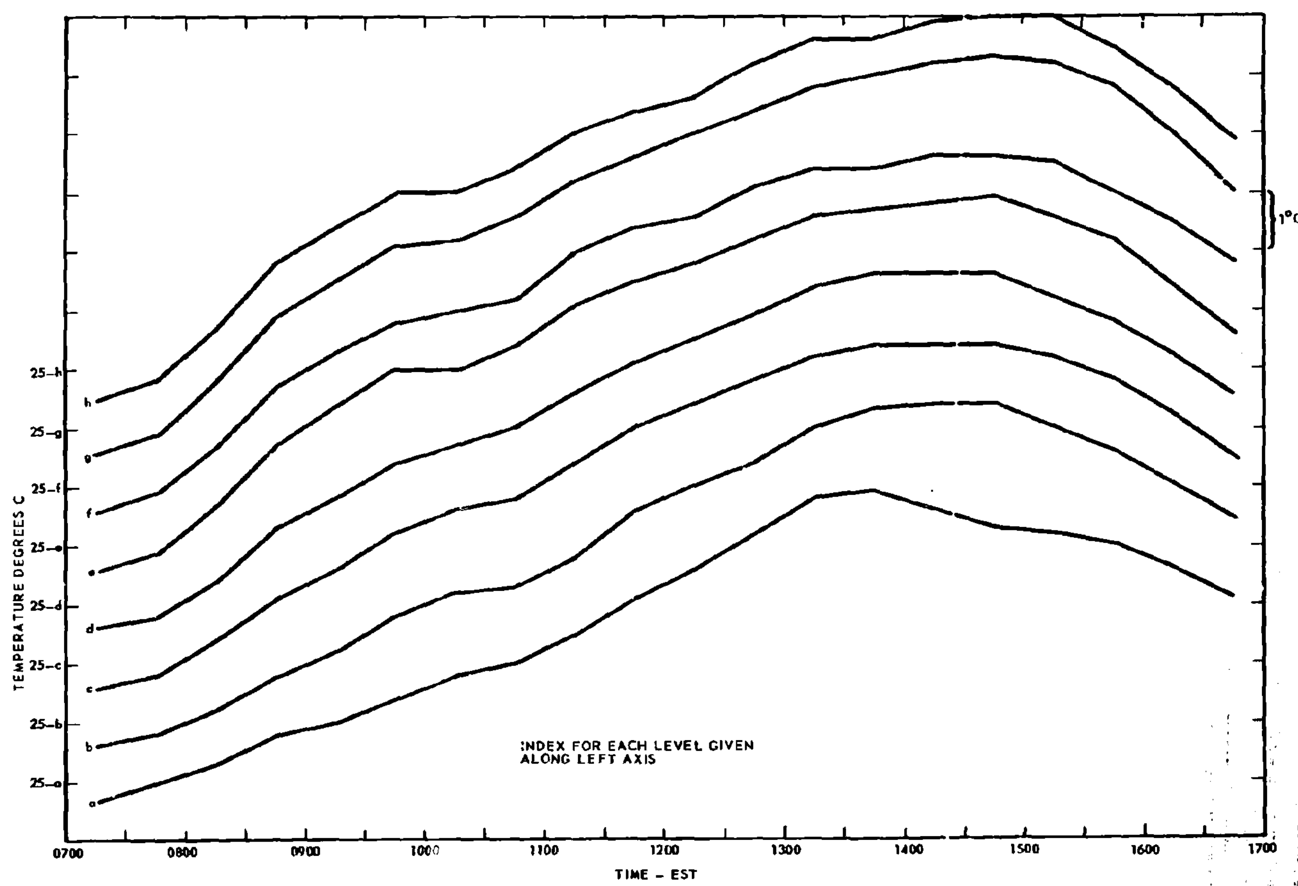


Figure 2-1 North Tower Temperatures, 12 March 1962, a Clear Day, by Levels

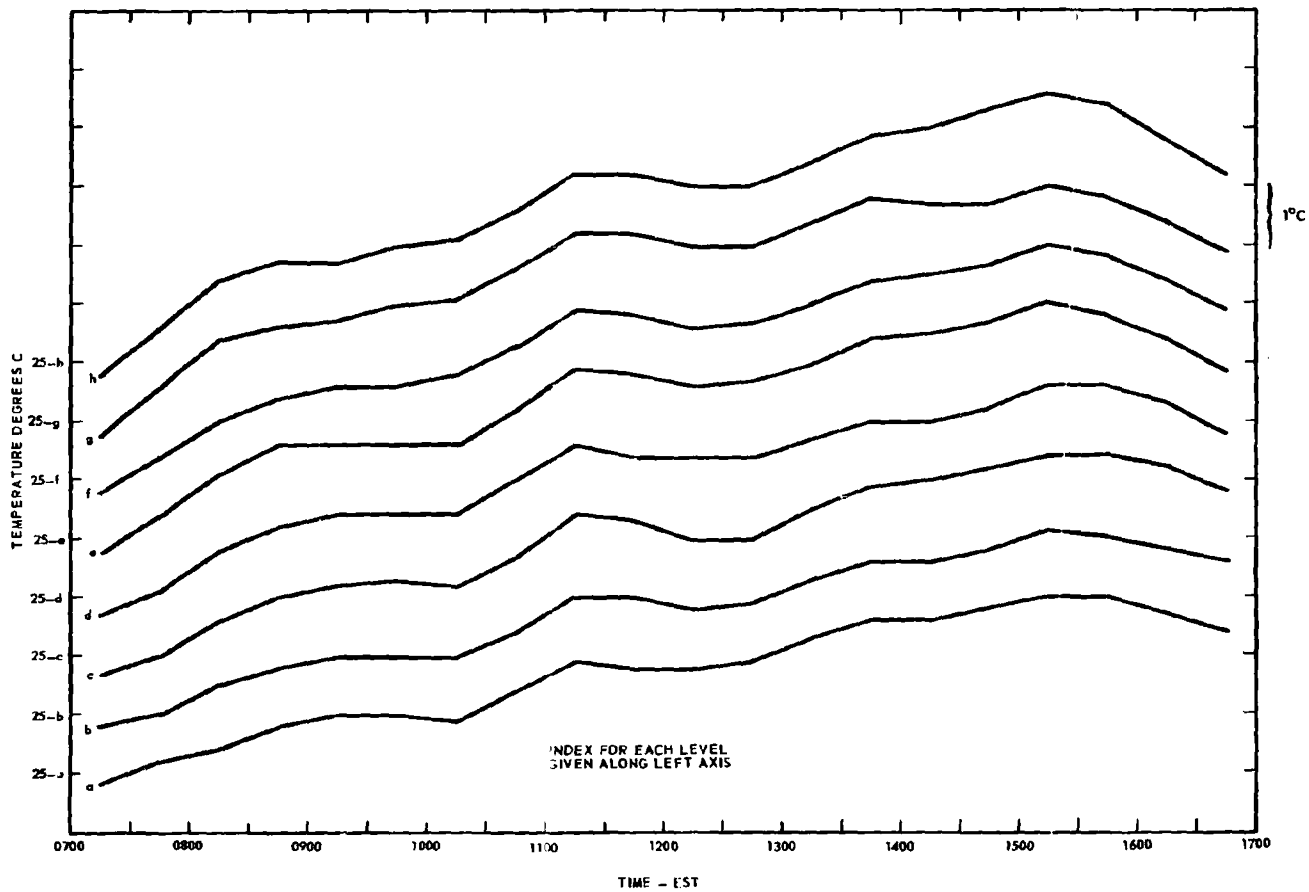


Figure 2-2 North Tower Temperatures by Levels on 12 April 1962, a Cloudy Day

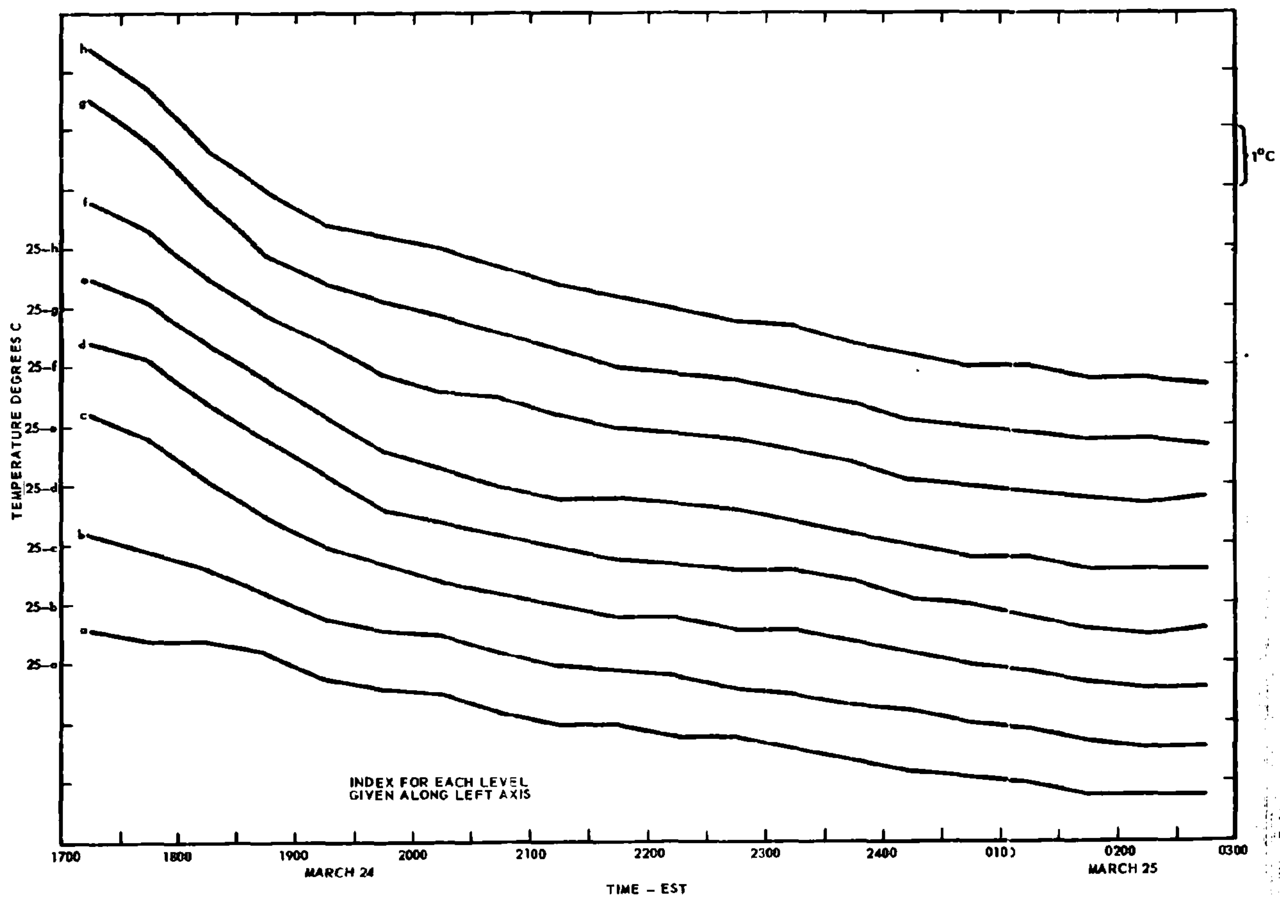


Figure 2-3 North Tower Temperatures by Levels on 24-25 March 1962, a Clear Night

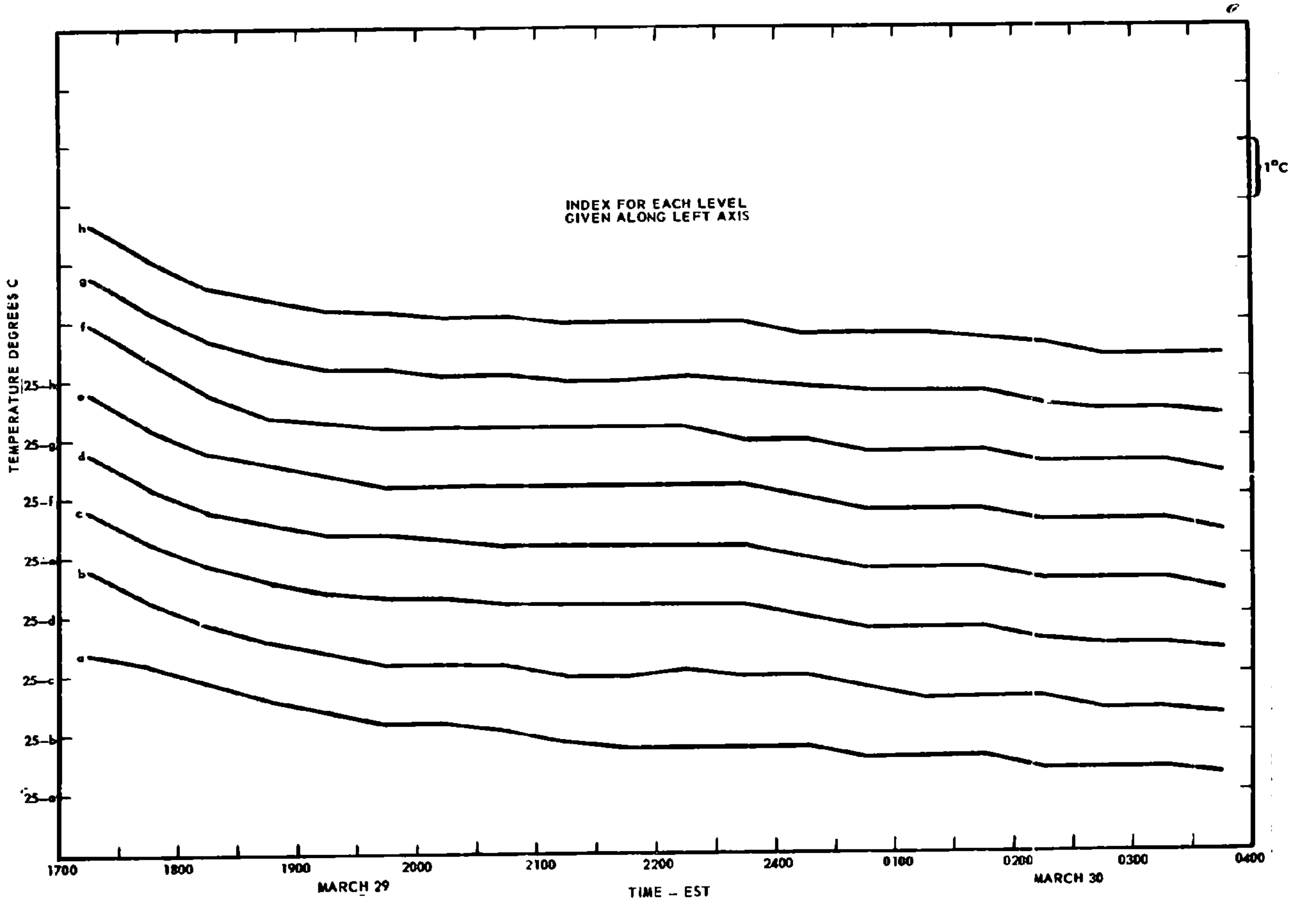


Figure 2-4 North Tower Temperatures by Levels on 29-30 March 1962, a Cloudy Night

be designated N and S for north and south. Comparisons may be made between the two towers at each of the eight levels. The procedure adopted was to make the comparison for the four periods referred to in Section 2.1 in order to find out whether the comparisons were affected by time of day.

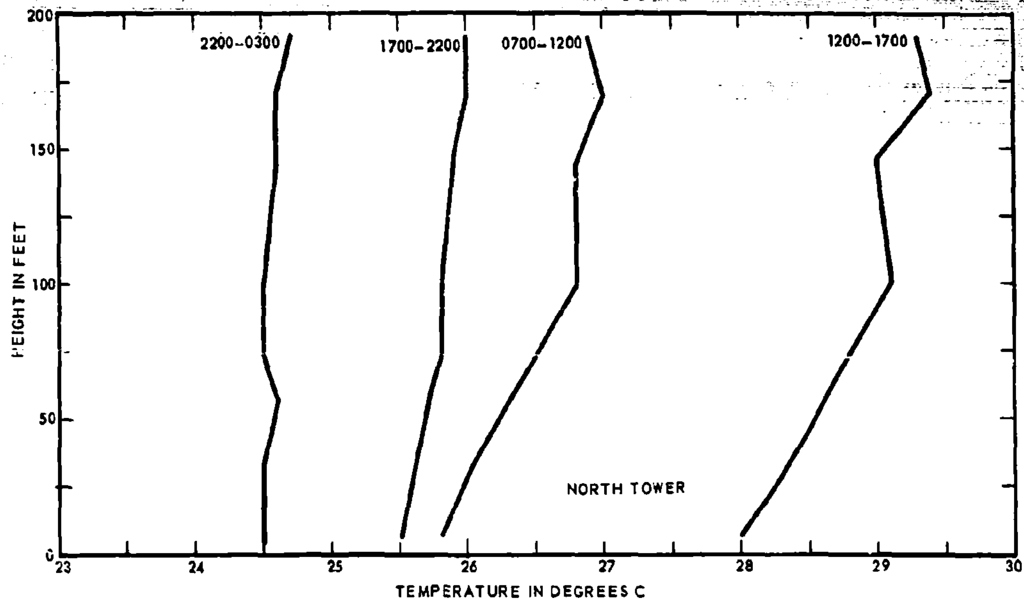
As an example, a description will be given of the procedure followed in comparing a-level temperatures during the period of rapid warming from 0700-1200. The data were obtained from the record of half-hourly temperatures for the four day trials on March 9, 12, and 15 and April 12. A correlation coefficient was computed between 39 paired temperatures, and the null hypothesis $T_N = T_S$ was also tested using the "t" test. The correlation coefficient was equal to .96, the mean a-level temperatures, correct to one decimal, were both 25.8C and it was inferred that $T_N = T_S$.

The procedure described above was then repeated for the other 7 levels. Thereupon the comparisons were performed again for the period 1200-1700 on samples of 40 paired temperatures, for the period 1700-2200 on samples of 90 paired temperatures, and finally for the period 2200-0300 on samples of 88 paired temperatures. The 1200-1700 data were obtained from the four day trials and the last two sets of data from the nine night trials. Table 2-1 gives the 64 mean temperatures which appear graphically in Figure 2-5 as mean temperature profiles for each time period.

The 32 correlation coefficients are given in Table 2-2. They are very high at all times of the day, but exceptionally high from 2200 to 0300 for such a large sample. Curiously the period 2200-0300 is also the one in which a uniform bias appears but the high correlation suggests that external warming and cooling influences are felt equally at the two towers. The correlation of .72 for the f-level at 1700-2200 stands out from all the rest, although no reason has been discovered for this divergence from the standard pattern.

Table 2-3 contains the tabulations of Student's "t" which were computed to test for identity of temperatures on the two towers. The so-called one-tail test was used because an assertion that the north tower temperature is colder than, or warmer than, the south tower is more informative than an assertion that temperatures on the two towers differ.

Some general trends are evident from Table 2-3 and Figure 2-5. During the day the north tower tends to be warmer than the south tower, whereas during the night it is colder (the period 1700-2200 is the transitional



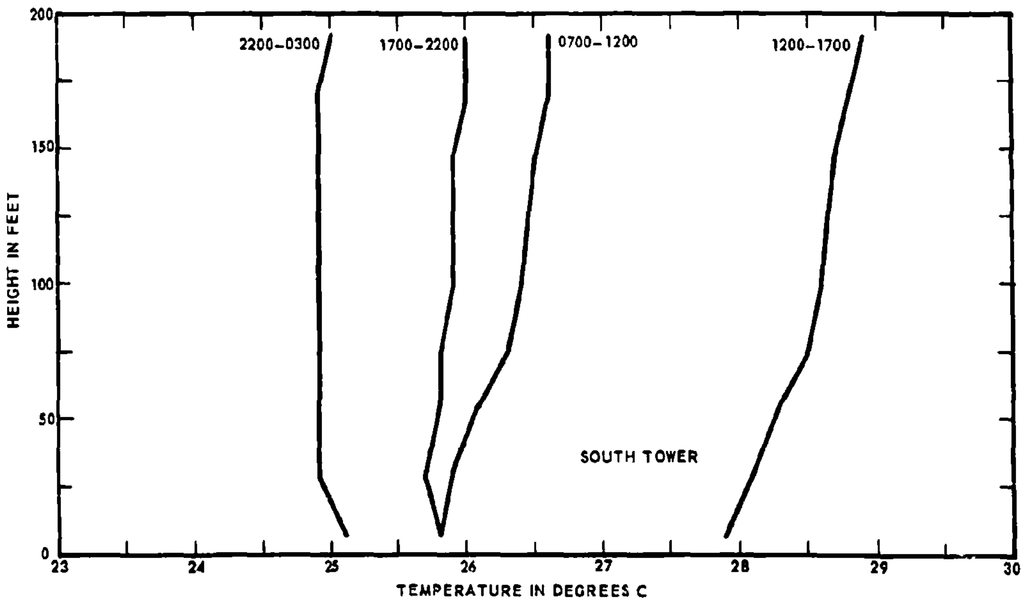


Figure 2-5 Mean Temperature Profiles for Selected 5-Hr Intervals, North Tower and South Tower

TABLE 2-1

MEAN CELSIUS TEMPERATURES AT THE NORTH AND SOUTH TOWERS BY LEVEL AND TIME OF DAY

Level	0700 - 1200		1200 - 1700		1700 - 2200		2200 - 0300	
	N	S	N	S	N	S	N	S
a 6.5 ft	25.8	25.8	28.0	27.9	25.5	25.8	24.5	25.1
b 30	26.0	25.9	28.4	28.1	25.6	25.7	24.5	24.9
c 56	26.3	26.1	28.6	28.3	25.7	25.8	24.6	24.9
d 74	26.5	26.3	28.8	28.5	25.8	25.8	24.5	24.9
e 100	26.8	26.4	29.1	28.6	25.8	25.9	24.5	24.9
f 146	26.8	26.5	29.0	28.7	25.9	25.9	24.6	24.9
g 170	27.0	26.6	29.4	28.8	26.0	26.0	24.6	24.9
h 192	26.9	26.6	29.3	28.9	26.0	26.0	24.7	25.0

TABLE 2-2

TABULATION OF CORRELATION COEFFICIENTS BETWEEN TEMPERATURE AT THE SAME LEVEL BUT ON DIFFERENT TOWERS BY TIME OF DAY AND LEVEL

Time	Sample Size	a	b	c	d	e	f	g	h
07-12	39	.96	.96	.97	.97	.96	.94	.97	.96
12-17	40	.94	.95	.96	.96	.97	.95	.95	.97
17-22	90	.86	.90	.89	.90	.92	.72	.93	.93
22-03	88	.96	.98	.98	.98	.99	.98	.98	.98

TABLE 2-3

TABULATIONS OF STUDENT'S "t" TO TEST THE HYPOTHESIS, $T_N = T_S$, AT EACH OF 8 LEVELS, BY TIME OF DAY

Time	Sample Size	a	b	c	d	e	f	g	h
07-12	39	-0.01	0.04	0.42	0.60	1.40	1.05	1.28	0.87
12-17	40	0.82	1.29	1.39	1.14	1.93*	1.53	2.41**	1.57
17-22	90	-3.02††	-1.21	-0.43	-0.28	-0.42	-0.55	0.02	-0.34
22-03	88	-5.55††	-3.39††	-2.87††	-2.70††	-2.82††	-2.35††	-2.13†	-2.24†

* 95% certain that T_N is warmer than T_S

** 99% certain that T_N is warmer than T_S

† 95% certain that T_N is colder than T_S

†† 99% certain that T_N is colder than T_S

period). Somewhat more cutting was done around the north tower than the south tower and the slightly greater opening is probably responsible for these minor temperature effects. Since even the statistically significant differences are small, it is clear from these results that a single temperature facility yields temperatures which are representative of this rain forest.

One other feature of the temperature profiles should be mentioned at this point. In Figure 2-5 it is evident, especially in the layer below 100 ft, that the warmest part of the day is characterized by the strongest below-canopy inversions. This is also the period of steepest lapse rates in the first few hundred feet above canopy. Moreover the coolest part of the day is also characterized by the strongest lapse below canopy and there is evident a regular steepening of the below-canopy inversion as one moves from the coldest to the warmest temperature profile on the figure. In the absence of any measurements of lapse rate in the first one to two thousand feet, this relationship becomes a useful indicator as follows. Above canopy instability increases in direct proportion to the increase in stability below canopy. This fact was made use of in the mathematical model developed in Volume I of this report.

2.3 INFLUENCE OF THE TREE-AIR INTERFACE ON TEMPERATURES

Temperature profiles in forest environments generally show patterns which are easily traced to the role played in radiative exchange by the tree-air interface. During the daytime. solar energy is absorbed at or slightly below the tops of the trees, as a result of which the height of maximum temperature is at or slightly below the tops. An inversion is present from the ground to the level of T_{max}, above which a superadiabatic lapse rate is found. During the night the top of the trees becomes the primary radiating surface for the forest and in time a slight lapse rate develops between the surface and the tree tops, with an inversion extending some distance above the trees. Figure 2-6 depicts the relationship between these typical day and night temperature profiles as they have been observed in other forests, in temperate latitudes.

From Figure 2-6 some properties of the interface may be listed as follows:

1. Daytime T_{max} is at or slightly below the interface
2. Nighttime T_{min} is at the interface
3. Maximum temperature range is at the interface.

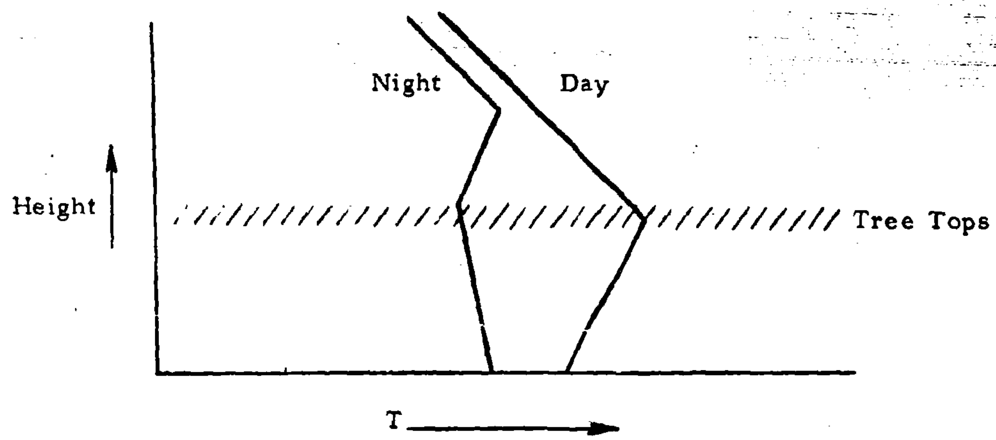


Figure 2-6 Typical Day and Night Temperature Profiles in a Forest Environment in Temperate Latitude

Temperature profiles reported in Table 2-1 and Figure 2-5 can be examined in the light of properties 1 and 2. However some additional data on temperature ranges are needed for comparison with property 3.

The facts on temperature ranges were developed as follows. For each 10-hour trial, the range of temperature was computed for all of the eight levels and for both towers. There were thus thirteen observations of the 10-hour temperature range for each level on each tower. In addition to this there were 72 hours of data* collected at the north tower only which yielded temperature ranges between 0700 and 1700 and 1700 to 0300. Six more observations were thus provided for the north tower. Mean ranges were computed for each level as shown in Table 2-4. Since day and night trials have been combined, the magnitude of the numbers is less indicative than their relative size, but relative size is exactly what is relevant to property 3 above.

The 146-ft level was just about at the treetop-air interface so it would be expected to show the properties mentioned above. However, from Table 2-1, 1200-1700, it is seen that the maximum daytime temperature is above the 146-ft level. Similarly, from Table 2-1, 2200-0300, it can be seen that the 146-ft level is not the level of minimum temperature. While differences from level to level are small, on the north tower the 146-ft level is not the coldest and on the south tower it shares the distinction with five other levels. From Table 2-4 it is apparent that the maximum temperature range at each tower occurs above the 146-ft level.

*These data are discussed in more detail in Section 5.

TABLE 2-4

OBSERVED MEAN 10-HOUR TEMPERATURE RANGES AT EIGHT LEVELS ON THE NORTH AND SOUTH TOWERS, IN DEGREES C

Level in feet	6.5	30	56	74	100	146	170	192
North Tower Range	2.85	3.17	3.39	3.53	3.67	3.68	3.85	3.92
South Tower Range	2.35	2.68	2.92	3.13	3.23	3.35	3.38	3.48

It thus becomes clear that the 146-ft level lacks the thermal characteristics that are usually associated with the interface. Moreover, there is no level that exhibits all three of the characteristics. The 192-ft level has the maximum temperature range on both towers, has the maximum daytime temperature on the south tower and second highest on the north tower, but also turns out to be the warmest rather than the coolest level at night. The 30-, 74-, and 100-ft levels are the coldest at night but none of these is either the warmest in the daytime or the level of maximum range. Tentatively one might conclude from the foregoing discussion that there are factors at work which interfere with a simple, radiatively induced temperature structure in the tropical forest. Some further clarification becomes possible in Section 5 where the results of the 72-hour study are discussed.

SECTION 3

WINDS

An identical set of sensors was installed on each tower to measure the winds. Included were a Beckman and Whitley vane and cup anemometer at 200 feet, and four anemometer bivanes installed at 6.5, 56, 74, and 146 feet. The Beckman and Whitley system provides direction and speed outputs which were recorded continuously on strip charts for several weeks, and on tape recorders during the thirteen 10-hour trials. The anemometer bivanes provide outputs of azimuth angle, elevation angle, and total wind speed which were recorded on magnetic tape during the thirteen trials only. Details of the construction, operation, and recording for both types of sensors are given in Section 6, Volume III of this report.

The Beckman and Whitley strip-chart records afford a means of studying macroclimatological wind factors and comparing the general climate of early 1962 to the norm described in Section 1. The records on magnetic tape were machine-processed to yield mean wind direction and standard deviation of wind direction, σ_θ. A 5-minute running mean was used in computing σ_θ and all other standard deviations. Although the anemometer bivane data were machine-processed, critical screening was required to sift out spurious data caused by tape noise and tape splices. All of the bivane data and taped Beckman and Whitley data discussed here have survived this critical screening process and provide a reliable, if limited, sample of the wind currents in the tropical rain forest.

3.1 200-FT WINDS

In Section 3.3 it will be shown that 200-ft wind directions at the north and south towers are well correlated. Accordingly this analysis has been performed on the data from one tower only, a series of measurements made at the north tower between 19 February and 21 April, 1962. The sample analyzed consists of 2257 mean half-hourly observations, which is approximately 80 percent of the population and therefore considered quite representative. The sample was analyzed to yield relative frequency

of different wind directions, and average speed for each hour of the day. The results are presented in Tables 3-1 and 3-2.

From Table 3-1 it is apparent that the northerly trade wind completely dominated the weather of early 1962. Table 1-2 indicated the average frequency of winds from NNW, N, and NNE to be about 50 percent at this time of year. In the study period, the nearly comparable sector 330-030 recorded a frequency of 69 percent.

Some influence of the north-south valley is also revealed in the data of Table 3-1. This is manifested in two ways. First of all, a secondary maximum in both frequency and speed appears at the sector 17-19 (includes winds from 165 to 195 degrees) directly opposed to the primary maximum at 35-01. Secondly, minima of both frequency and speed appear at the two cross-valley sectors 08-10 and 26-28.

Table 3-2 shows the minimum speed occurring shortly after dawn and a flat maximum covering 3 hours during the afternoon. An abrupt increase in speed occurs between the 8th and 11th hours and an equally abrupt decrease between the 22nd and 1st hours.

3.2 WIND PROFILES

Difficulties with the anemometer bivane-tape recorder system resulted in a considerable loss of data. For details of this loss the reader is referred to Section 6, Volume III of this report. Careful screening of machine-processed data has eliminated all questionable values, leaving a smaller sample of reliable data. From these data, two types of profiles have been constructed, namely profiles of mean speed for each trial, and, for five trials, consecutive half-hourly profiles of speed and direction. For most trials, data for half-hourly periods 2 through 11 were used to construct the mean speed profiles, but in some instances breaks in the record necessitated slight adjustments in the periods used. The profiles of speed and direction for selected tests were constructed for the consecutive half-hourly intervals, 5, 6 and 7.

Mean wind speeds for the 13 trials are shown for both towers in Table 3-3 and Figures 3-1 and 3-2. The speed transducer for the B and W sensor at the south tower failed on 5 March after several days of operation. Efforts to repair it in the field were unsuccessful. However, comparison of wind speeds during the period that both were operating indicates a good agreement between towers. Thus the 200-ft wind speed on the north tower is used for both towers in Figures 3-1 and 3-2.

TABLE 3-1 RELATIVE FREQUENCY AND MEAN SPEED OF 200- FT WIND AS OBSERVED FROM 19 FEBRUARY TO 21 APRIL 1962, BY 30 DEGREE SECTORS (35-01 INCLUDES WINDS FROM 345 TO 015 DEGREES)

Sector	35-01	02-04	05-07	08-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	32-34
Frequency (%)	41.8	11.9	1.9	1.0	2.0	2.3	6.6	1.8	2.3	3.3	4.6	20.3
Mean Speed (mi/hr)	9.9	7.6	4.5	2.2	4.1	4.5	5.2	4.0	3.5	2.3	4.2	8.5

TABLE 3-2 MEAN SPEED OF 200-FT WIND, 19 FEBRUARY TO 21 APRIL 1962, BY HOURS

Hour Ending	01	02	03	04	05	06	07	08	09	10	11	12
Speed mi/hr	6.7	6.3	6.2	6.3	5.9	6.0	5.9	5.7	6.4	7.3	8.5	8.7
Hour Ending	13	14	15	16	17	18	19	20	21	22	23	24
Speed mi/hr	9.2	9.5	9.5	9.5	9.4	9.2	9.4	8.8	8.7	8.4	7.6	7.2

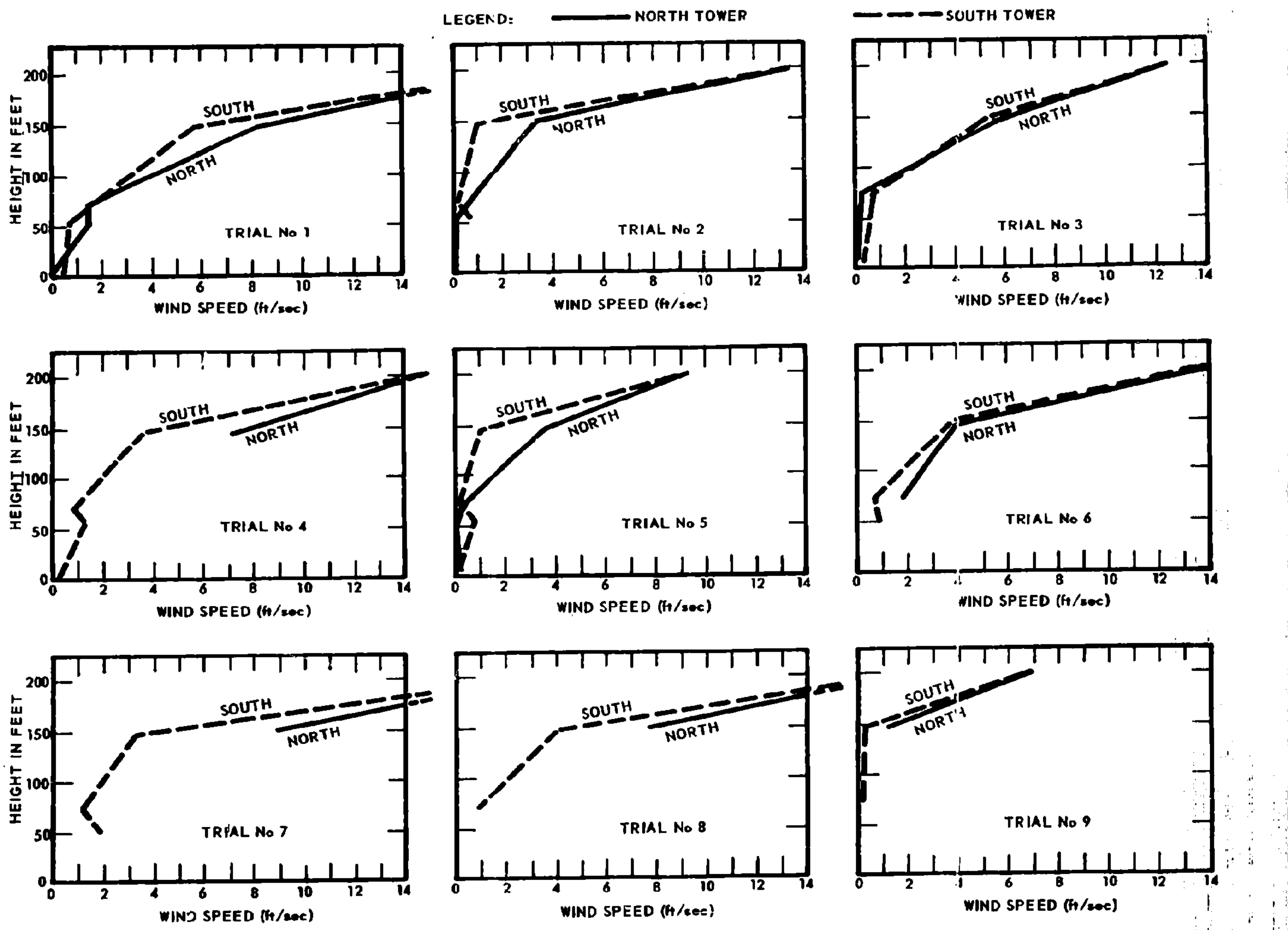


Figure 3-1 Mean Horizontal Wind Speed Profiles, by Trials (1-9)

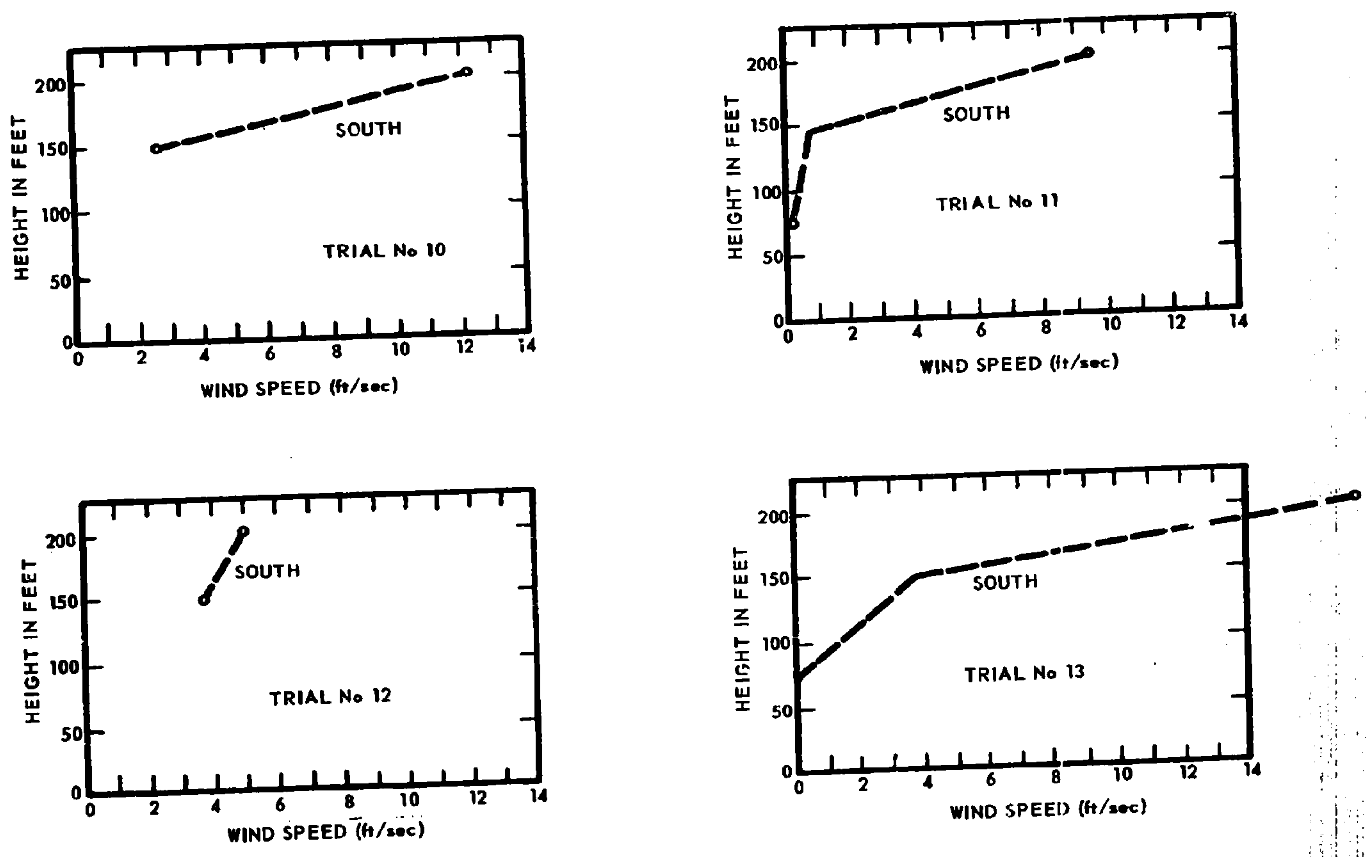


Figure 3-2 Mean Horizontal Wind Speed Profiles, by Trials (10-13)

Three points are apparent on examination of Table 3-3 and Figures 3-1 and 3-2:

1. The south tower winds (especially at the 146-foot level) are much weaker than the north tower winds. Vegetation near the south tower was denser, and less cutting was done in setting up the south tower, which accounts for these lighter winds.

2. A very steep gradient exists between 200 feet and the top of the canopy (approximately 146 feet), somewhat less gradient through the crown of the tallest trees, then a very shallow gradient down to the 6.5-foot level. In several tests an apparent reversal of the trend appears in the profile near the 74-foot level. This was especially true of the south tower, but occurred occasionally at the north tower. In a later paragraph it will be shown that this reversal appears in the mean profile for all the tests. Although variations in the density of vegetation could induce this effect, it is so slight here as to leave its significance in doubt.

3. Trials 5, 9, 11, and 12 are the only trials where the 200-foot wind is less than 10 ft/sec.

The deterioration of electronic equipment in this environment of high humidity, high temperature, and high fungus activity is also evident from the increasing amount of missing data with the increasing number of trials.

The missing data made it difficult to construct a single mean profile of the thirteen tests. By expressing each speed in Table 3-3 as a percentage of the 200-foot wind for that trial, a set of numbers was generated that could be averaged to compute a mean profile. This profile is shown in Figure 3-3. Since it is based on data from both towers, it is representative of the whole array. In this figure the wind speed as a percent of the 200-foot wind is plotted against height. A second speed scale in ft/sec, showing the mean 200-foot wind equal to 100 percent, allows the mean speed for each level to be read in ft/sec or in percent of 200-ft wind. A slight reversal in the profile between 56 and 74 ft is shown in the profile. The lighter wind at 74 feet may be due to denser vegetation at the base of the main canopy, but inherent variability of the data may be responsible. It can also be observed that in the mean, the wind at the 6.5-foot level is very slightly less than 1 percent of the 200-foot wind

TABLE 3-3

MEAN WIND SPEED IN FT/SEC AT FIVE LEVELS FOR BOTH TOWERS, BY TRIALS (MEANS ARE FOR 5-HOURS BASED ON HALF-HOURLY PERIODS 2 THROUGH 11)

Trial	Tower	6.5 Ft.	56 Ft.	74 Ft.	146 Ft.	200 Ft.
1	N	0.10	1.50	1.50	8.18	18.90
	S	0.49	0.73	1.53	5.65	MSG
2	N	0.09	0.06	0.80	3.35	13.41
	S	MSG	0.65	0.21	0.99	MSG
3	N	0.07	0.18	0.10	5.73	12.38
	S	0.27	1.43	MSG	5.26	MSG
4	N	MSG	MSG	MSG	7.13	14.78
	S	0.28	1.20	0.71	3.59	MSG
5	N	0.13	0.05	0.31	3.56	9.32
	S	0.16	0.74	0.17	1.03	MSG
6	N	MSG	MSG	1.74	3.91	13.87
	S	MSG	0.86	0.61	3.65	MSG
7	N	MSG	MSG	MSG	8.99	19.33
	S	MSG	1.77	1.10	3.32	MSG
8	N	MSG	MSG	MSG	7.71	18.33
	S	MSG	MSG	1.02	4.14	MSG
9	N	MSG	MSG	MSG	1.12	6.89
	S	MSG	MSG	0.09	0.23	MSG
10	N	MSG	MSG	MSG	MSG	12.17
	S	MSG	MSG	MSG	2.58	MSG
11	N	MSG	MSG	MSG	MSG	9.53
	S	MSG	MSG	0.24	0.81	MSG
12	N	MSG	MSG	MSG	MSG	4.99
	S	0	MSG	MSG	3.68	MSG
13	N	MSG	MSG	MSG	MSG	17.31
	S	MSG	MSG	0.12	3.77	MSG

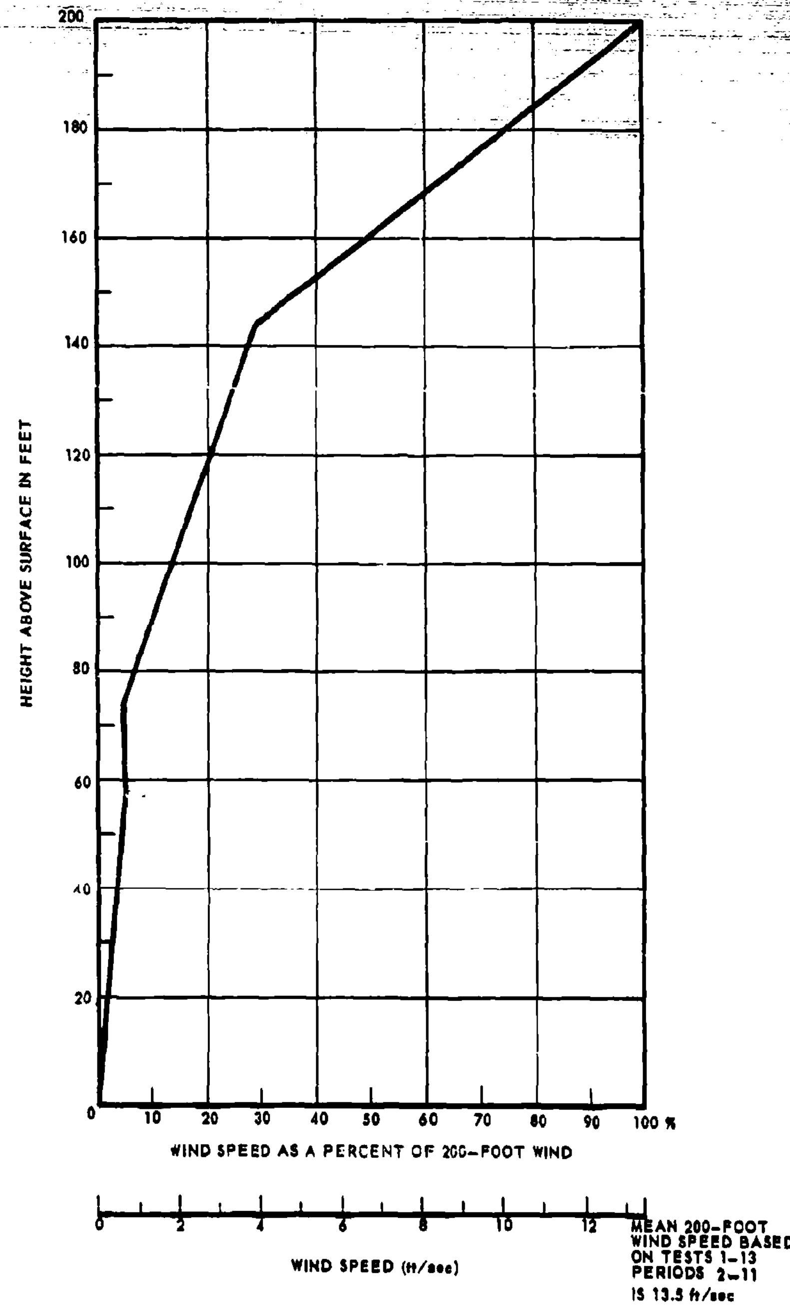


Figure 3-3 Mean Wind Speed Profile Based on All Trials

and the 56-foot and 74-foot winds are about 5 percent of the 200-foot wind. These estimates are likely to be slightly low because of the high frequency of winds less than the sensor's starting speed. All such winds are treated as zero and introduce a negative bias.

In order to indicate the variation of the wind profile with time, the 5th, 6th and 7th half-hourly intervals of trials 1, 2, 3, 4 and 6 were investigated and profiles of speed and direction were constructed. These profiles for the north and south towers are shown in Figures 3-4 through 3-8. As might be expected, only small variations in speed occur between consecutive half hours. Larger variations exist between consecutive half-hourly directions, particularly below the canopy attesting to some randomness of the air currents. Further evidence of randomness in the below-canopy air currents is presented in the following section.

3.3 CORRELATION OF WIND DIRECTION BETWEEN THE NORTH AND SOUTH TOWERS

It is desirable to know whether or not the wind direction under the canopy is a conservative property with distance. A correlation coefficient between simultaneous wind directions at any one level on the two towers will provide the answer. Therefore, twenty-five half-hourly mean wind directions were compared for each bivane level and for 200 feet. Approximately 3/5 of the points came from trial 1, 1/5 from trial 3, and the remainder were selected at random from trials 2, 3, 4 and 6. The results are presented in Figure 3-9 as a profile of the square of the correlation coefficient versus height.

The value of r^2 indicates what proportion of the variance at the south tower can be accounted for by variations at the north tower. In this application a high value at any height indicates organized wind currents at that height while a low value indicates random air currents. In general it may be said that values of $r^2 < .50$ suggest that useful correlations do not exist since more than half of the variance remains unaccounted for.

It is immediately evident from Figure 3-9 that no useful correlation exists between wind direction on the two towers below the top of the canopy. Immediately above the canopy, r^2 is of the order of 0.8, but decreases rapidly through the canopy to an average value of about .17. From 74 feet to the surface, r^2 is never greater than 0.26. It is concluded that air currents below the canopy are random, and above the canopy are well organized.

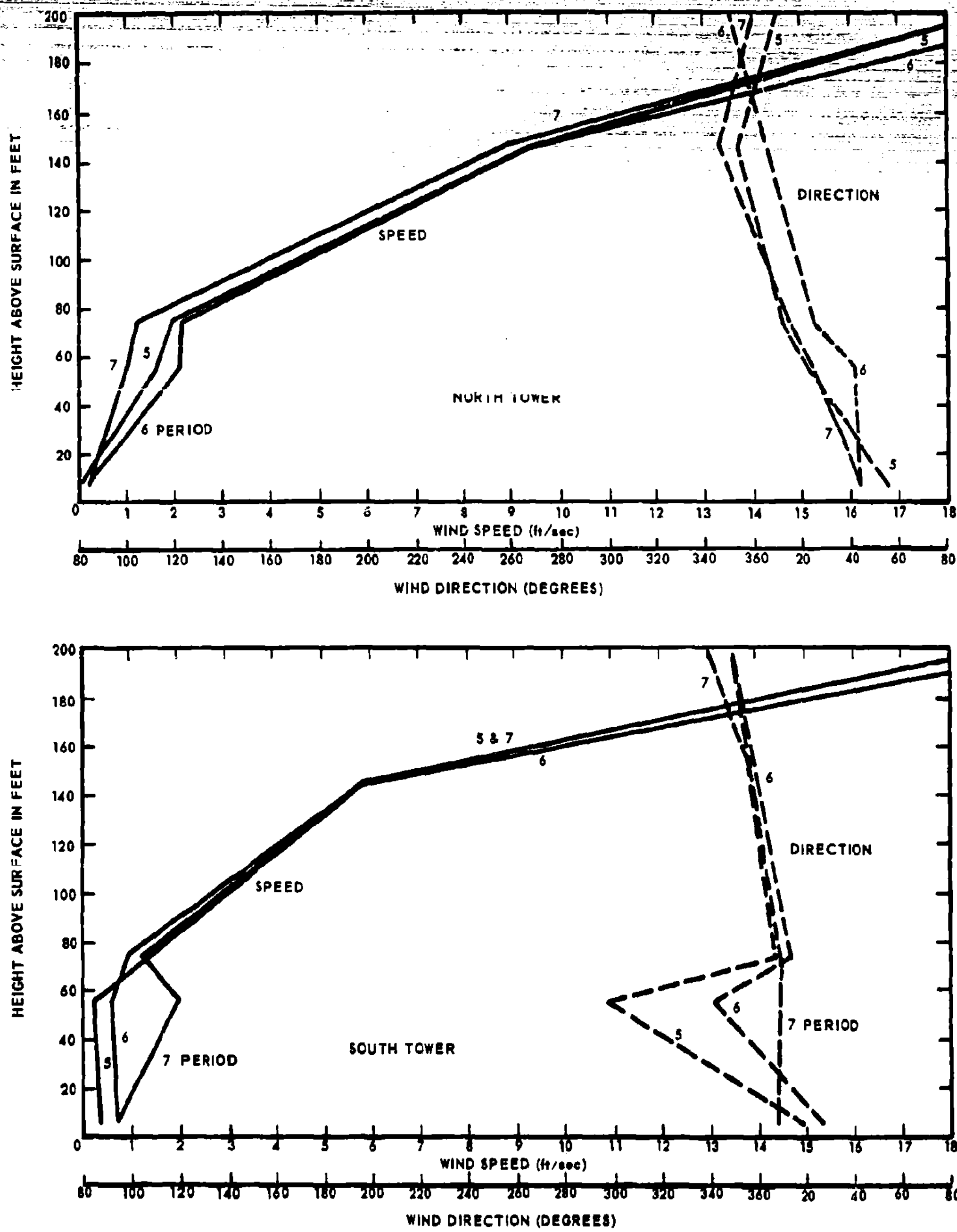


Figure 3-4 Profiles of Horizontal Wind Speed and Direction Showing Variation with Time (Trial #1 Day)

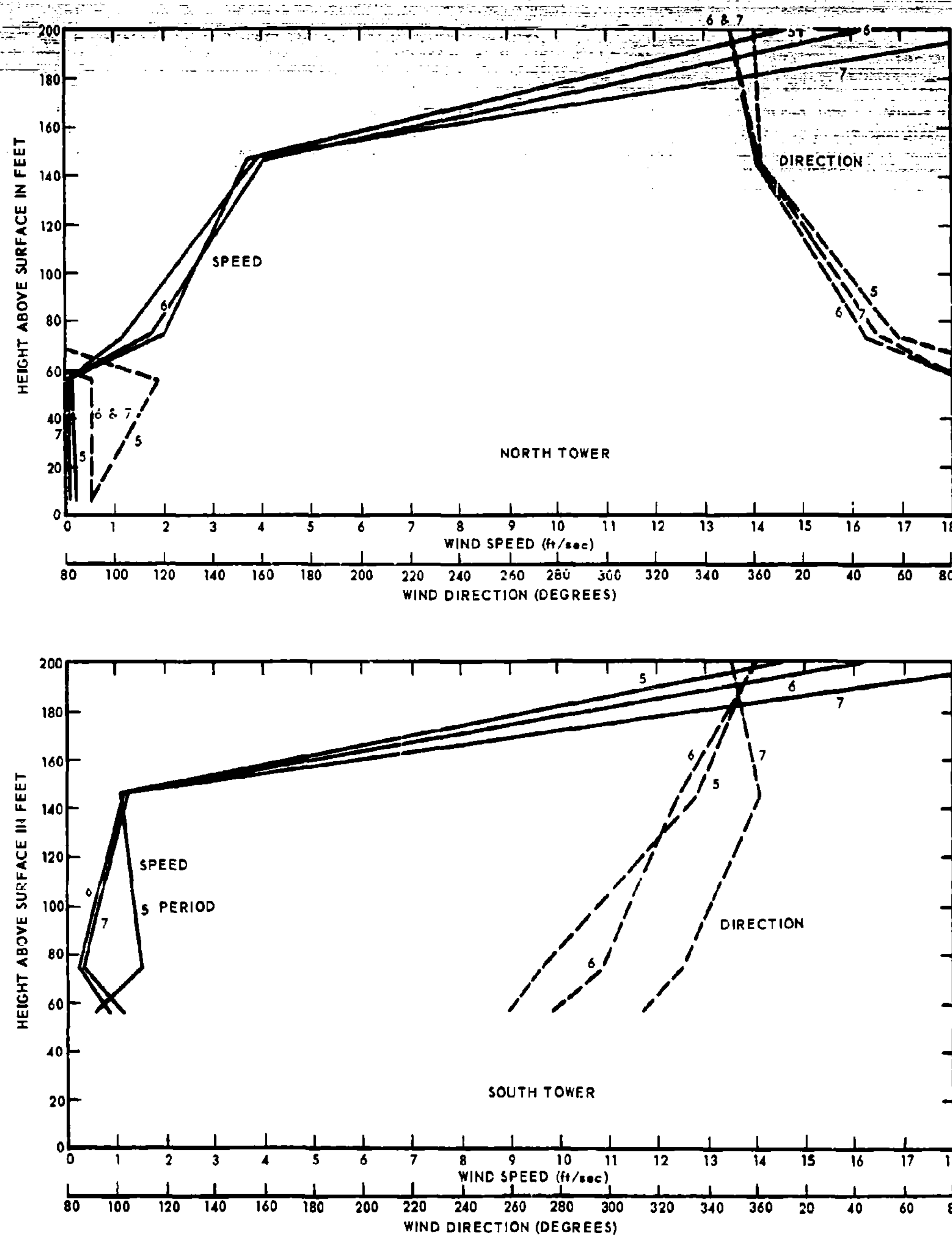


Figure 3-5 Profiles of Horizontal Wind Speed and Direction Showing Variation with Time (Trial #2 Day)

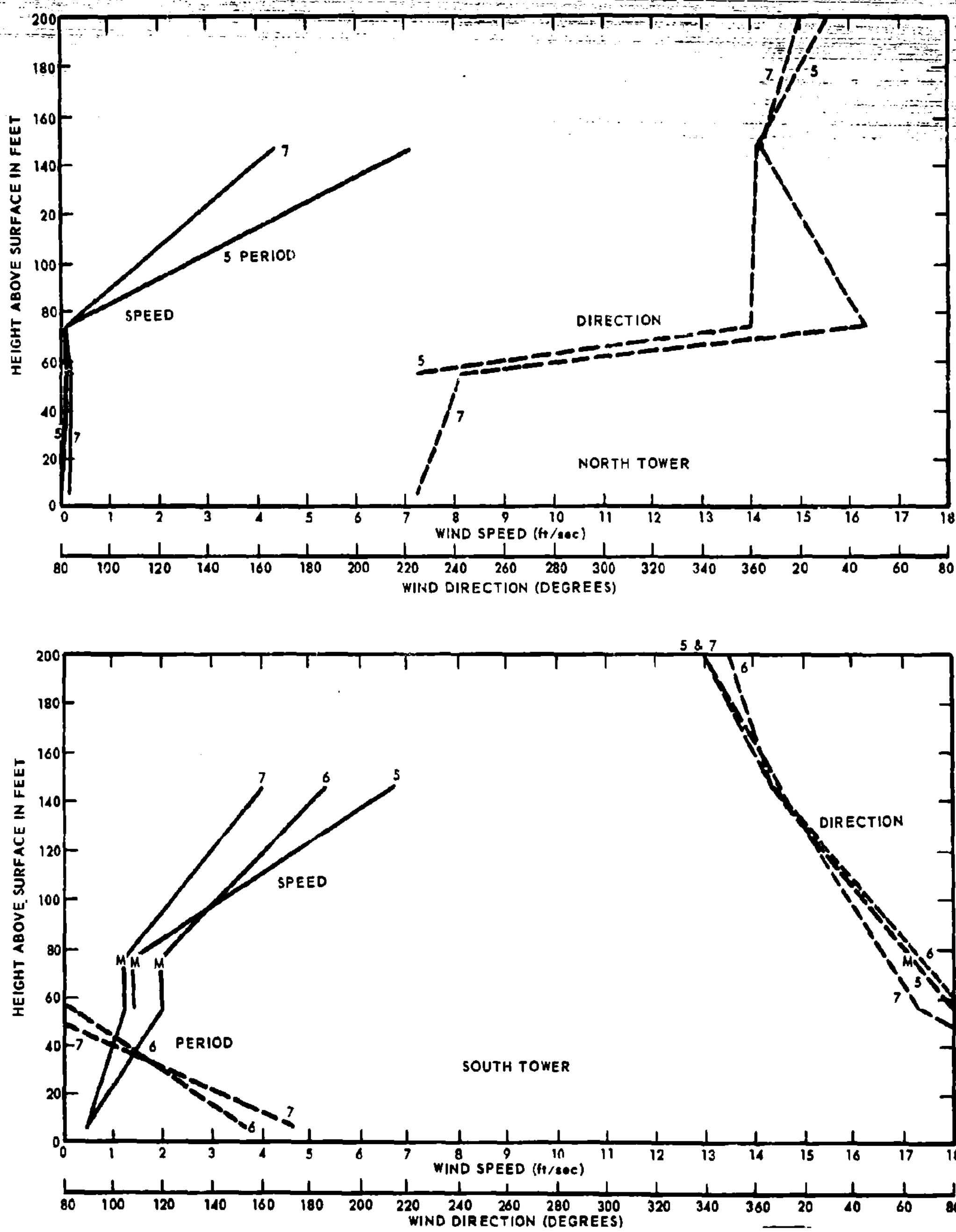


Figure 3-6 Profiles of Horizontal Wind Speed and Direction Showing Variation with Time (Trial #3 Day)

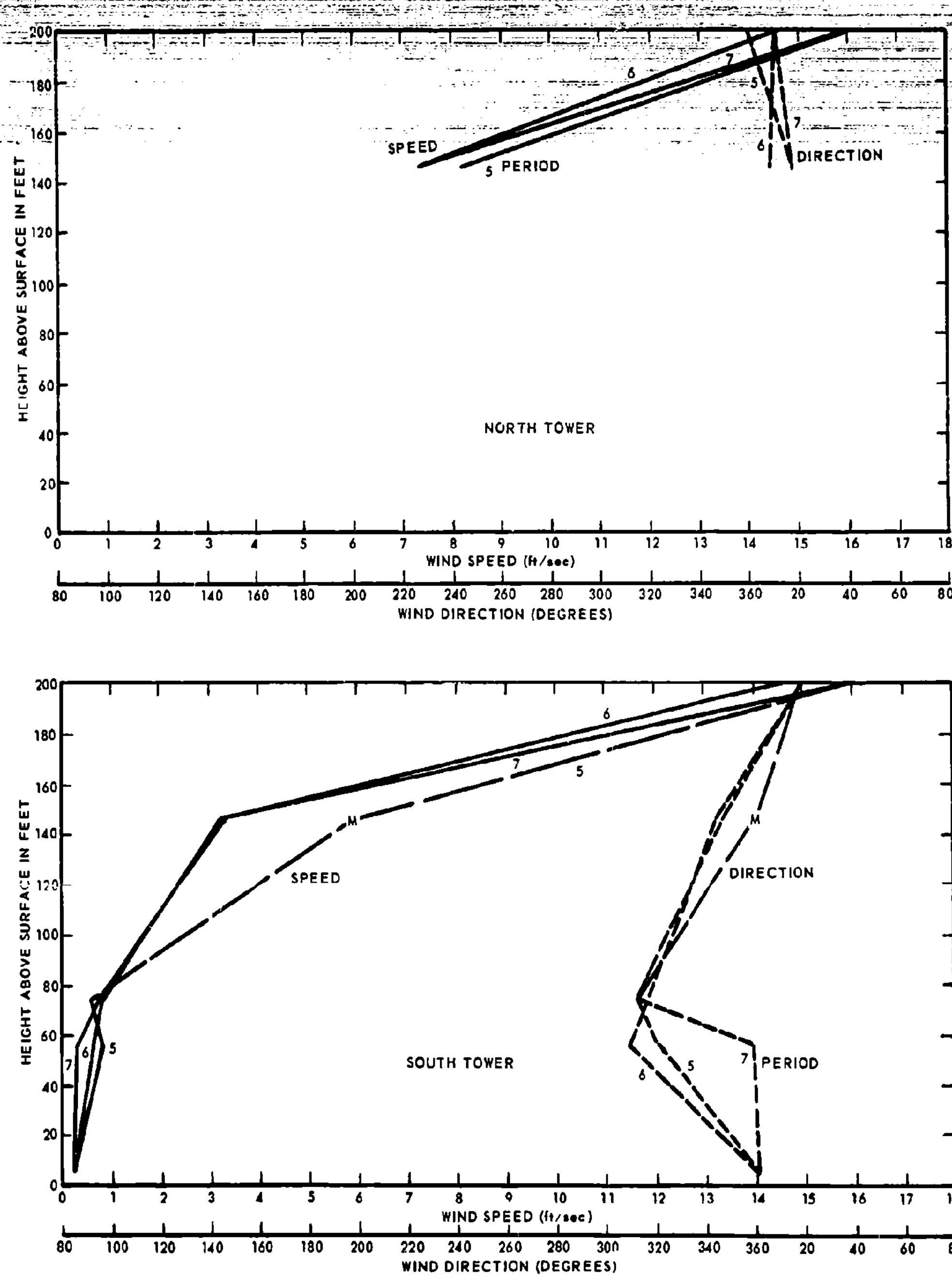


Figure 3-7 Profiles of Horizontal Wind Speed and Direction Showing Variation with Time (Trial #6 Night)

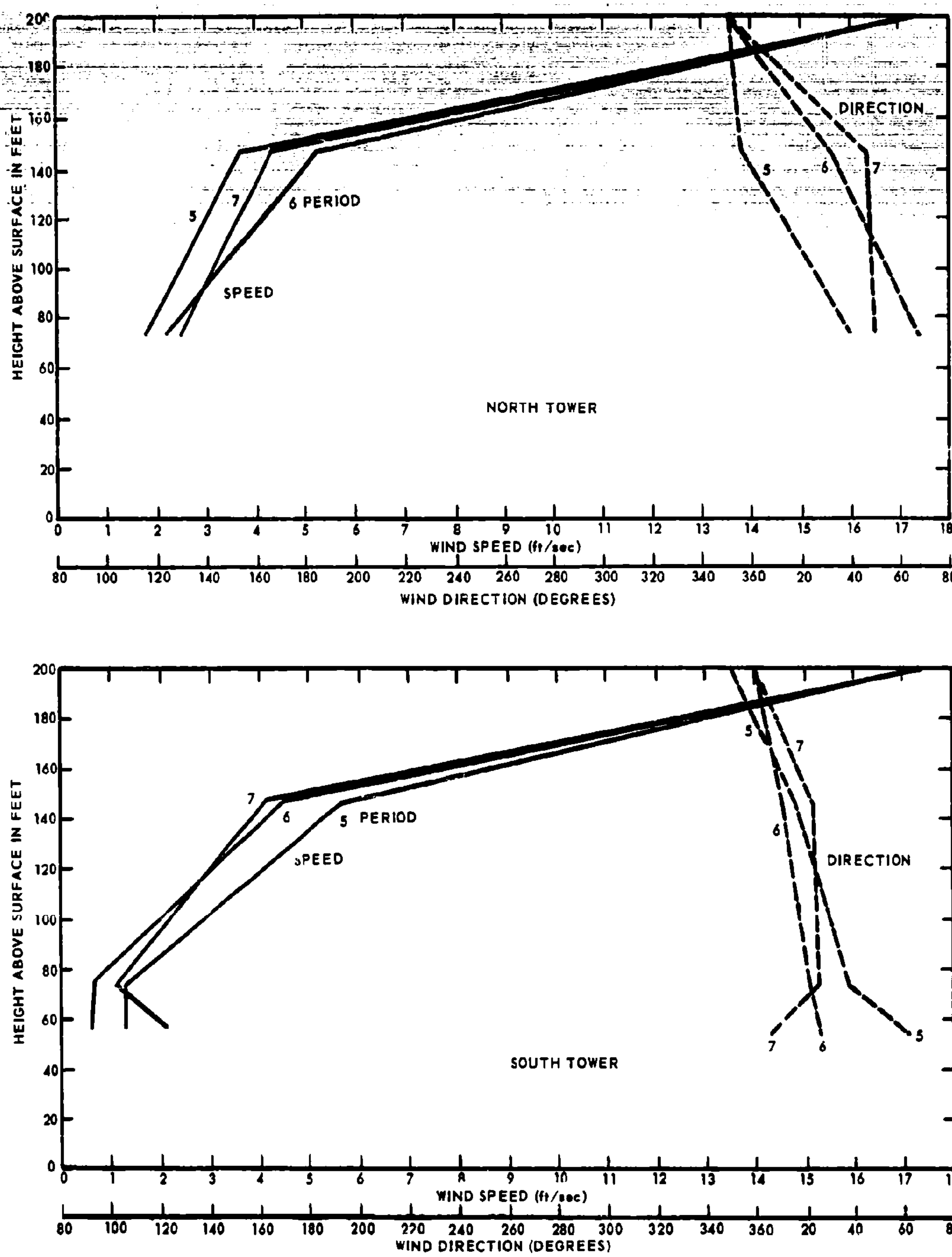


Figure 3-8 Profiles of Horizontal Wind Speed and Direction Showing Variation with Time (Trial #6 Night)

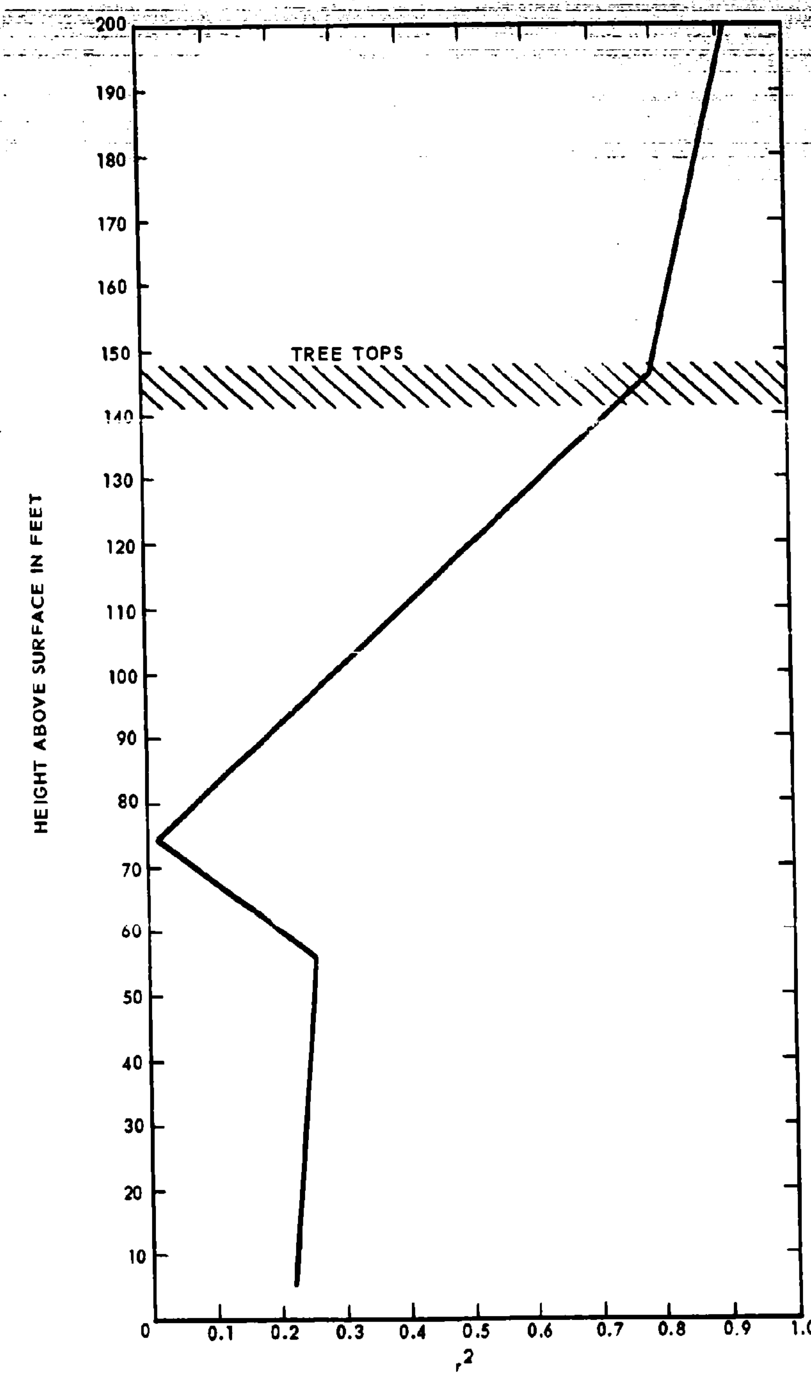


Figure 3-9 Square of the Correlation Coefficient, r, between North and South Tower Wind Direction vs Height

SECTION 4

RAINFALL

The advance party had moved into the camp site on the Rio León in October, during the rainy season. The weather remained rainy throughout November and December and during that time no records were kept. However, the river was constantly overflowing its banks. The rainy season broke abruptly on 2 January 1962 and fine weather prevailed for the next 8 weeks, while the river dropped about 12 ft.

It was 7 March before a tipping bucket rain gage was placed in operation. However, occurrences of rainfall were noted at the campsite during the interval 12 February - 16 March 1962. There are thus two kinds of rainfall statistics that may be analyzed. One consists of occurrences according to time of day as observed at the camp clearing, and the other consists of amounts, in hundredths of an inch, by time of day, as measured on the north tower just above the canopy.

The observations of rain occurrences were part of a 5-week program of observations of temperature, dewpoint, and weather made at the camp clearing during the final weeks of preparation for the field trials. The temperature observations were made daily at 0700, 1300, and 1900, and at each observation a note was made of any rain during the previous 6 hours. The results of these observations are summarized in Table 4-1.

TABLE 4-1

OCCURRENCES OF RAIN, AND NO RAIN BY TIME OF DAY AT THE LEÓN CAMPSITE, 12 FEBRUARY TO 16 MARCH 1962

	6 hrs Ending 0700	6 hrs Ending 1300	6 hrs Ending 1900
Rain	17	9	3
No Rain	15	23	30

It should be remarked that most of the rain occurrences covered in Table 4-1 were very light and did little more than wet the ground. However these occurrences had a very marked tendency to take place at night.

Beginning 7 March, rainfall was recorded at the north tower by an operations pen installed in the Beckman and Whitley wind recorder. Every .01 inch of rain actuated the pen, thus providing an easily processed record except when excessive rates of rainfall caused the individual pen marks to merge. Amounts having not been measured until 7 March it is estimated that rainfall from 3 January to 6 March totaled about 0.5 to 1.0 inches. Thereafter the weather was unsettled and occasional heavy rains were recorded. The dates of occurrences and the total daily amounts of rainfall are given in Table 4-2 and Figure 4-1 for the period 6 March to 21 April.

TABLE 4-2

TOTAL 24-HOUR RAINFALL IN INCHES AS MEASURED ABOVE RAIN FOREST AND DATE OF OCCURRENCE

March	6	7	10	11	14	19	20	21	22	25	31	Total
Rainfall	.06	1.46	.08	.07	.17	1.15	2.76	2.98	.22	.02	.48	9.45
April	1	3	4	5	6	7	15	17	19	20	21	
Rainfall	.86	.49	.04	.05	.11	.01	.08	.02	2.40	.32	.01	4.39

Rates of rainfall were at times quite large, but not exceptional, compared to those in temperate latitudes. The five largest half-hourly rainfalls that were recorded were 0.85, 0.72, 0.69, 0.63, and 0.60 inches. The tipping bucket gage is known to underestimate these large rates, but even allowing for this, the rates would not be excessive. The feature that makes them seem impressive to the on-the-scene observer is that they are not attended by gales and thunder.

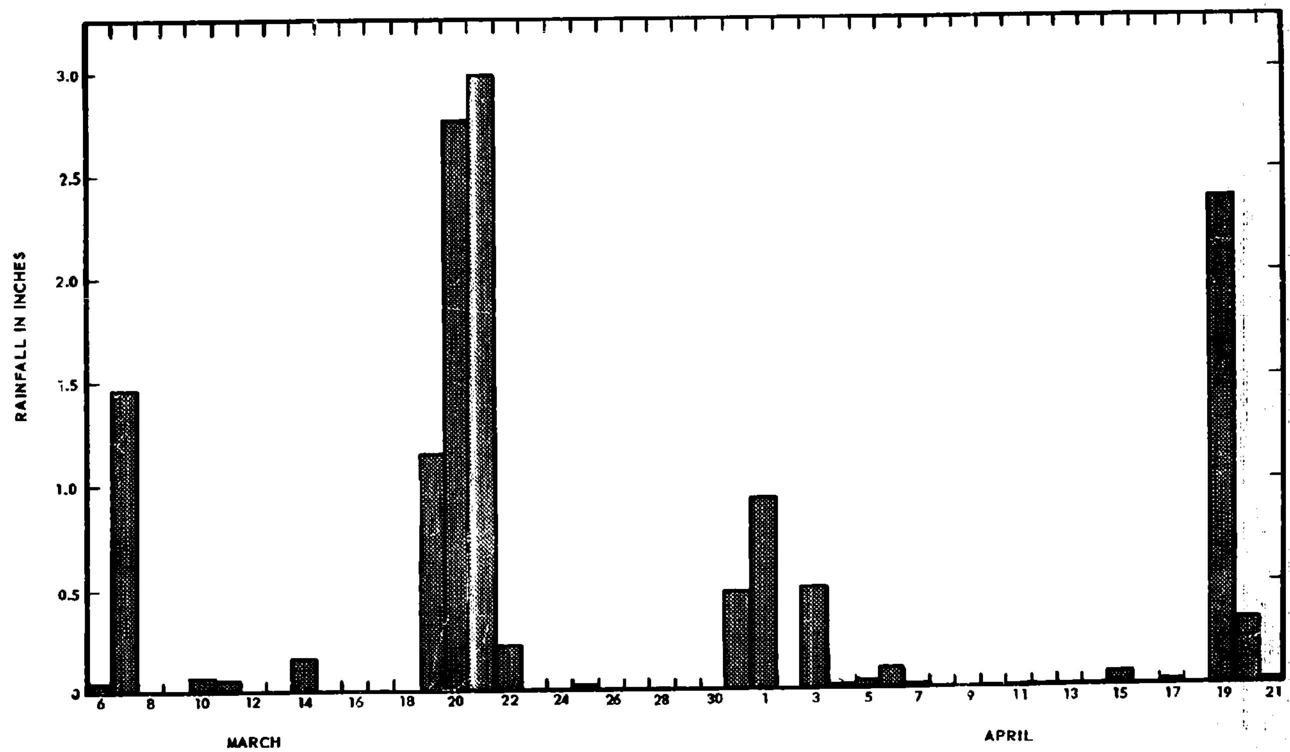


Figure 4-1 24-Hr Rainfall Totals, 6 March - 21 April 1962

SECTION 5

THE 72-HOUR METEOROLOGICAL RUN

The primary objective of the field program was to investigate the ventilation of a rain forest by a tracer technique. Between 9 March and 13 April, during thirteen tracer-diffusion trails, micrometeorological data were collected on both 200-foot towers. In the intervals between trials, only the rain gage and the Beckman and Whitley wind system were operating. Consequently the record of wind and temperature profiles consisted of thirteen 10-hour segments covering only the hours from 0700 through midnight to 0300.

After the diffusion trials a supplementary collection of meteorological data was performed for 72 consecutive hours at the north tower. During this interval there was an attempt to operate all meteorological sensors. The occurrence of rain in well-defined bursts during the 72 hours sheds important new light on the temperature profiles, and fully justified the additional effort.

The 72-hour run, coming after mid-April, appears to have been in the transitional period between the dry and wet seasons. Between 19 February and 21 April, 74 percent of the 200-foot winds were from the sector 320° to 040° which is typical of the dry season, but during the 72-hour run only 30 percent of the winds were from the same sector, and rain fell for almost one third of the time. The distinction between wet and dry season is not one of air mass, however, and the observed conditions are in many ways representative of the rain forest at all times. Detailed accounts of the several elements observed during the 72 hours are contained in the following sections.

5.1 TEMPERATURES

Half-hourly mean temperatures were determined, as described in Section 2, for the eight tower levels a through h. Since the absolute top of all trees in the vicinity of the north tower was just under 150 feet, levels a through e (100 ft) may be considered within the forest, levels f,

g, and h (146, 170 and 192 ft), above the forest. Temperatures for the eight levels are plotted against time in Figure 5-1a.

In this figure a common scale of 1°C per main division is used for all eight temperatures, but crossing over of adjacent graphs has been avoided by separating the temperature index for adjacent levels by 1°. The location of the 20°C index for each level is shown along the ordinate scale.

The most striking thing about the set of graphs is how consistently inflections appear at all levels at the same time. The same behavior was observed during the thirteen penetration trials. One may examine the common shape of the eight graphs and note that the first full day (April 19) exhibited an irregular and suppressed daytime rise. The second day showed a well-developed rise until 1300 EST, followed shortly after by an abrupt drop. On the third day a strong diurnal rise was apparently combined with an overall warming as temperatures at the end of the run were generally 2-3°C warmer than 24 hours earlier. It is an interesting oddity that the temperatures of 21.3°C and 31.8°C observed at the 192-foot level around 0600 EST and 1600 EST on April 21 were the coldest and warmest observed on the tower at any time during the entire field program.

For purposes of analysis the 72 hours will be separated into seven periods of cooling or warming as follows:

(1)	Cooling	April 181730E-190330
(2)	Warming	191130E-191530
(3)	Cooling	191530E-200500
(4)	Warming	200530E-201230
(5)	Cooling	201300E-202300
(6)	Warming	210730E-211430
(7)	Cooling	211530E-212000

The magnitude of these seven major temperature oscillations increases from 6.5 ft through 192 ft as shown in Table 5-1. This pattern

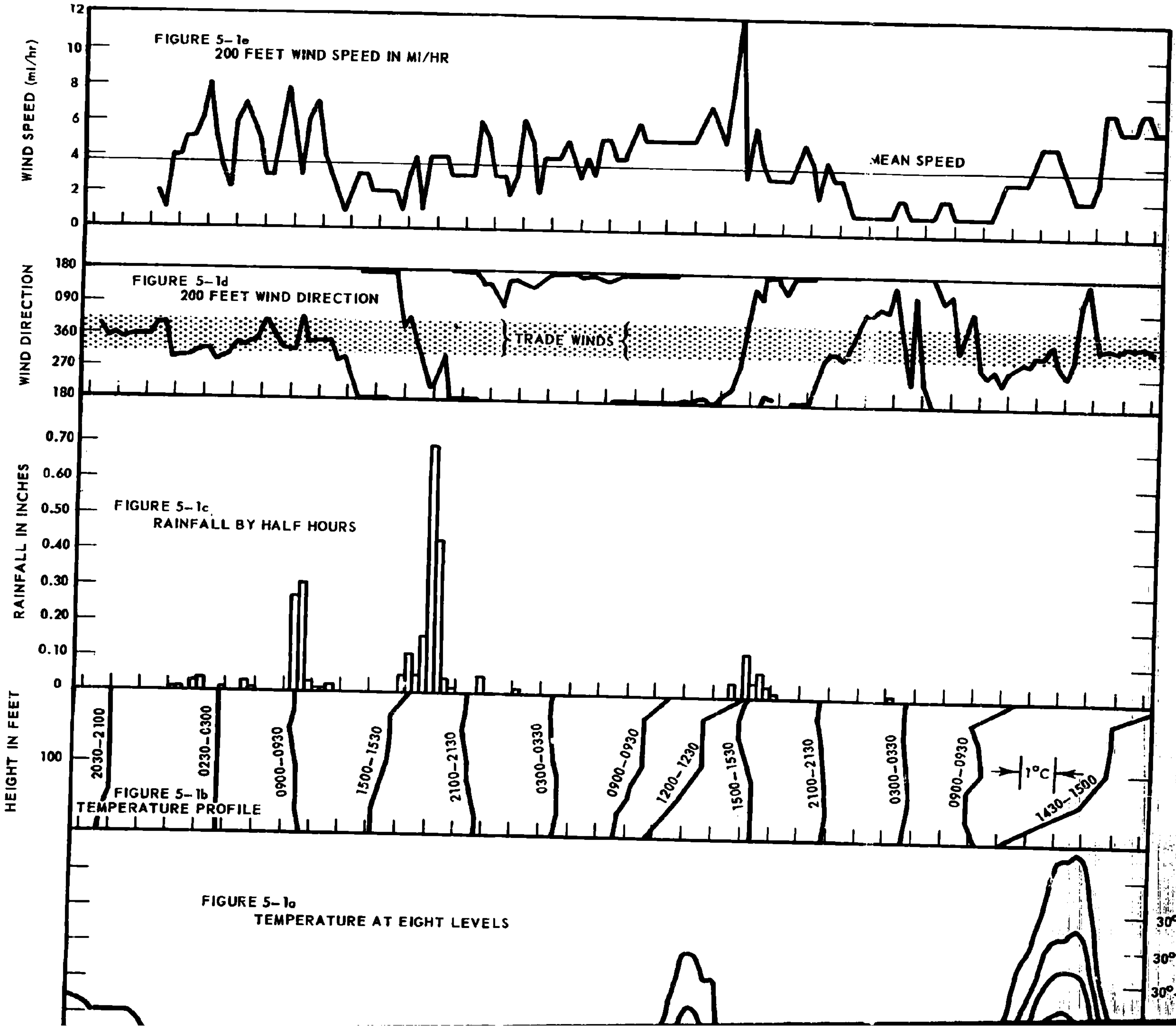


FIGURE 5-1e
200 FEET WIND SPEED IN MI/HR
WIND SPEED (mi/hr)
12
10
8
6
4
2
0
MEAN SPEED
FIGURE 5-1d
200 FEET WIND DIRECTION
WIND DIRECTION
180
090
360
270
180
TRADE WINDS
FIGURE 5-1c
RAINFALL BY HALF HOURS
RAINFALL IN INCHES
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
FIGURE 5-1b
TEMPERATURE PROFILE
HEIGHT IN FEET
100
2030-2100
0230-0300
0900-0930
1500-1530
2100-2130
0300-0330
0900-0930
1200-1230
1500-1530
2100-2130
0300-0330
0900-0930
1°C
1430-1500
FIGURE 5-1a
TEMPERATURE AT EIGHT LEVELS
30°-h
30°-g
30°-f

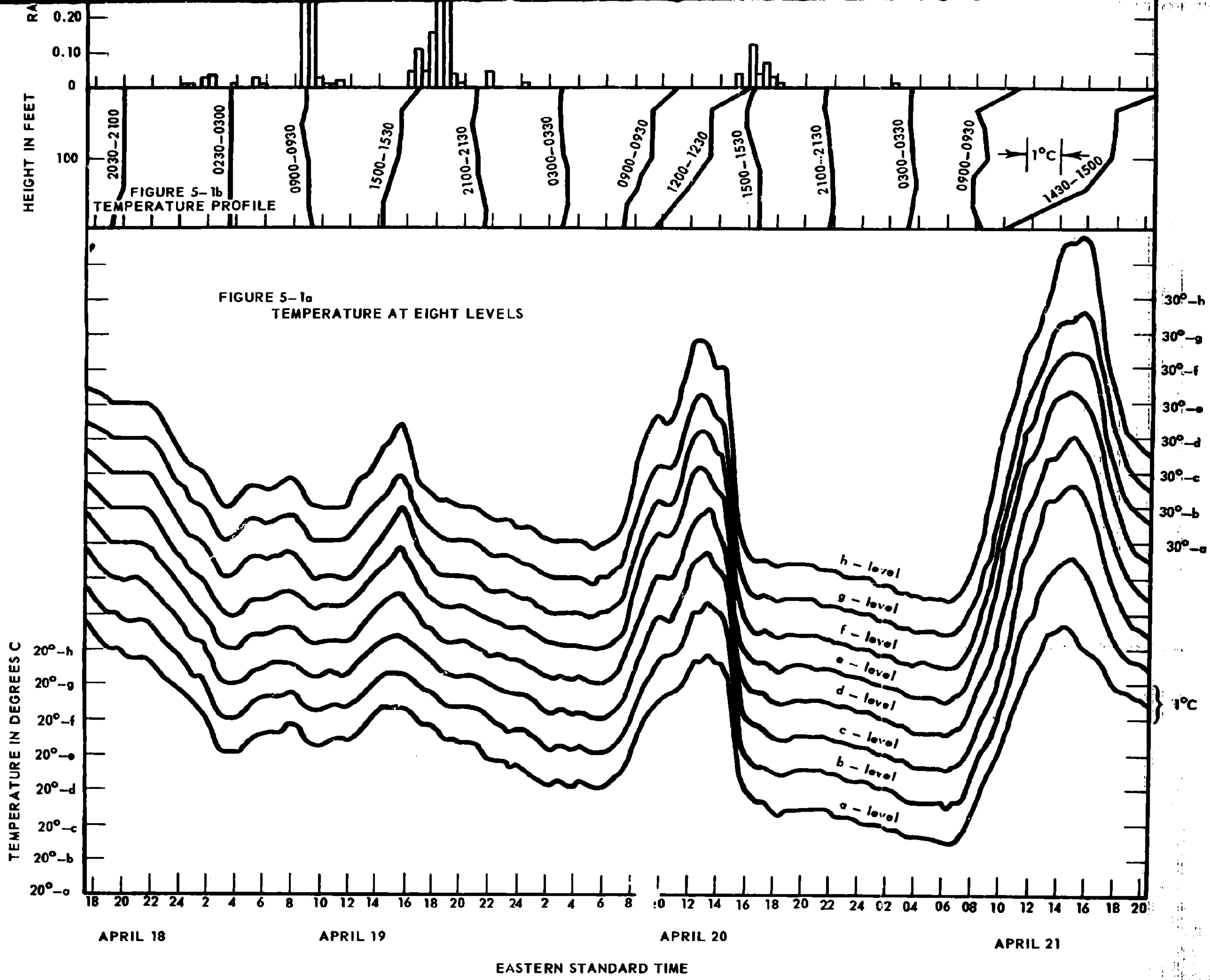


Figure 5-1 Observed Values of Variables During 72 Hour Test, 18-21 April, 1962

is partly anomalous since the maximum temperature oscillations would be expected at the top of the forest, i. e. , 146 ft (as discussed in Section 2. 3) rather than nearly 50 feet above the forest.

TABLE 5-1

OBSERVED TEMPERATURE RANGE IN DEGREES CELSIUS AT EACH OF EIGHT LEVELS DURING PERIODS OF COOLING AND WARMING

Period \ Level	6. 5 ft	30 ft	56 ft	74 ft	100 ft	146 ft	170 ft	192 ft
1	3. 7	3. 7	3. 7	3. 7	3. 6	3. 6	3. 4	3. 4
2	0. 9	1. 0	1. 2	1. 4	1. 7	2. 1	2. 0	2. 4
3	2. 3	2. 3	2. 4	2. 6	2. 9	3. 1	3. 2	3. 6
4	3. 8	4. 3	4. 8	5. 0	5. 1	5. 3	5. 4	6. 0
5	4. 7	5. 1	5. 6	5. 8	5. 9	6. 2	6. 2	6. 8
6	5. 6	6. 6	7. 6	7. 9	8. 2	8. 4	8. 6	9. 8
7	2. 2	3. 2	4. 2	4. 6	4. 9	4. 8	5. 0	6. 2
Mean as % of range at 192 ft	60. 7	68. 5	77. 2	81. 1	84. 5	87. 6	88. 5	100

A general idea of the variation in temperature profiles can be gained from Figure 5-1b which shows the observed temperature profiles at fourteen different times through the 72-hour run. By comparing this with the course of temperature in Figure 5-1a it is seen that inversions are associated with periods of warming, and isothermal or slight lapse conditions with periods of cooling.

A more detailed picture can be gained from Figures 5-2 and 5-3 in which are portrayed the changes of lapse rate within each of the seven major periods of cooling and warming. The dry adiabatic lapse rate is

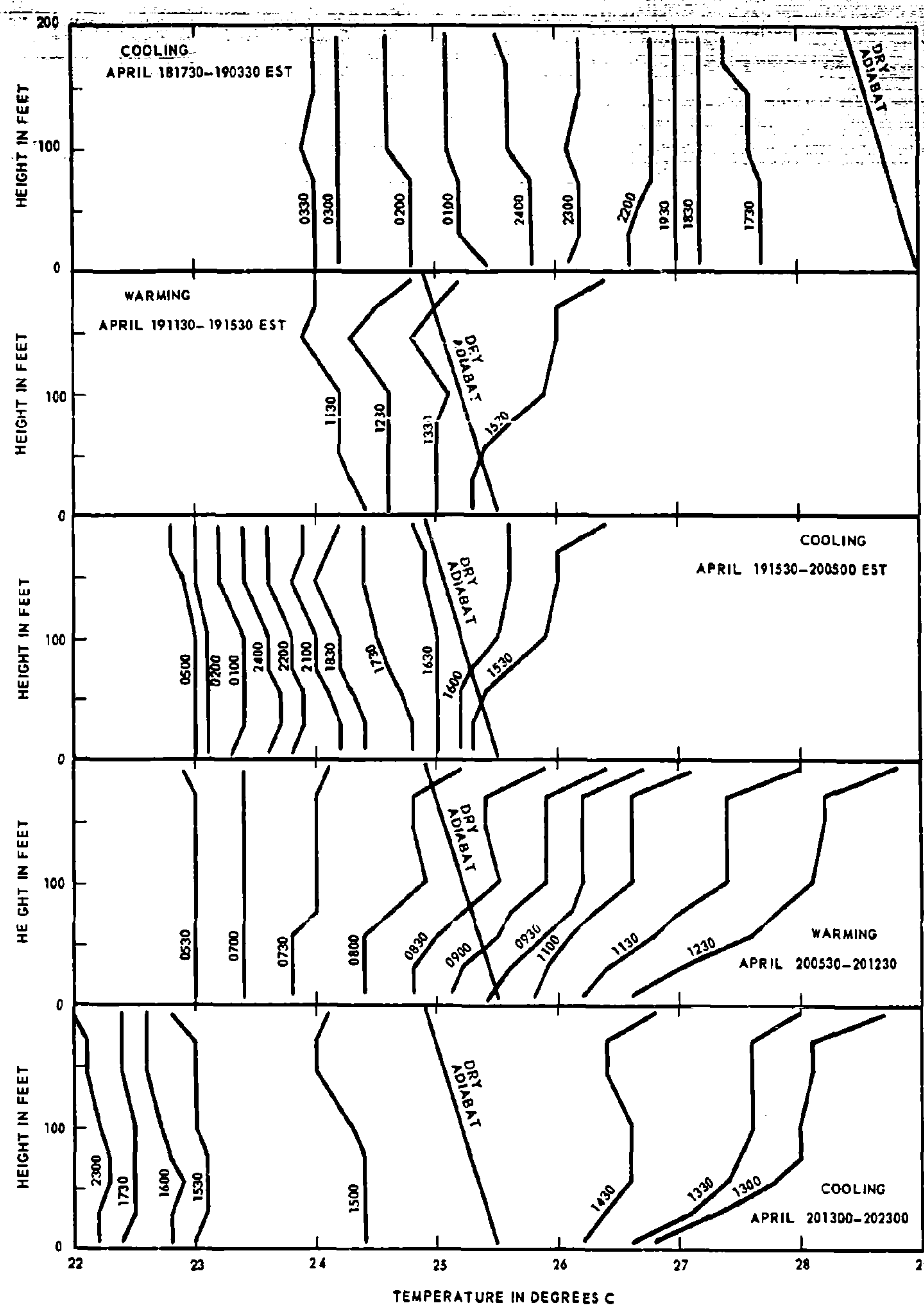


Figure 5-2 Changes of Lapse Rate During Five Cooling and Warming Cycles

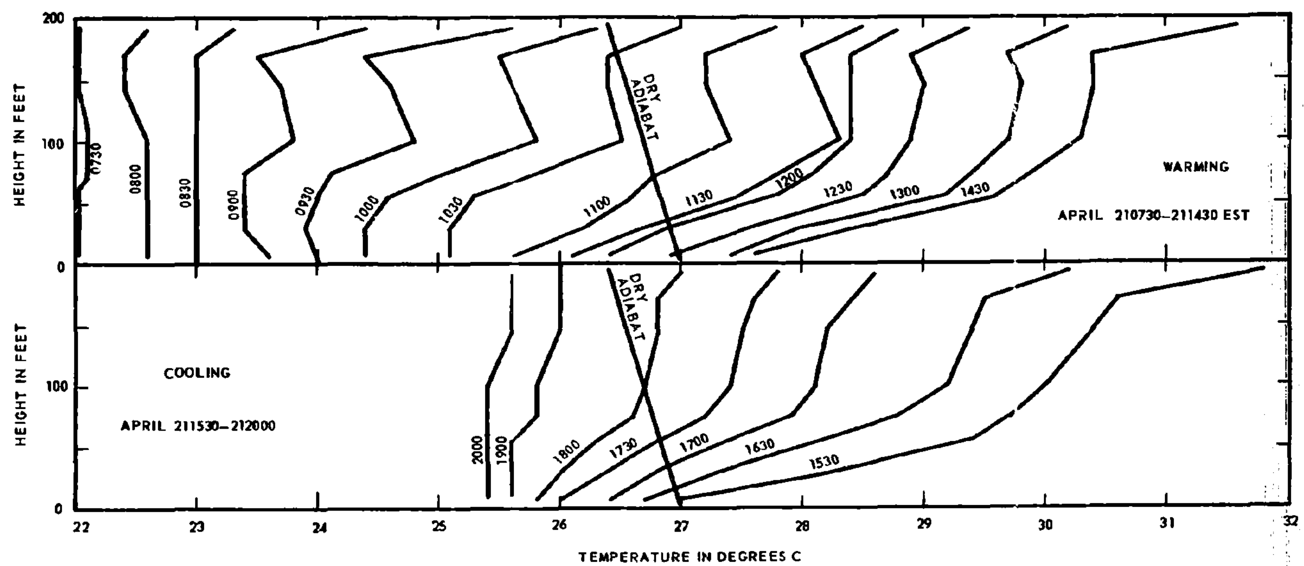


Figure 5-3 Changes of Lapse Rate During Two Cycles of Warming and Cooling

plotted as a reference in each period. In these figures it is even more evident that inversions between the surface and 200 feet develop and intensify during warming and gradually disappear during cooling.

There are other curious results such as the development of maximum temperatures at the highest elevation during warming even though the interface, where heat is presumably introduced, is below 150 feet. This had already been observed on the south tower during the penetration trials, but up until the 72-hour run, 170 feet had been the level of maximum temperature on the north tower. Another oddity is the frequent appearance of a steep lapse rate between 100 and 146 feet. This is most strikingly illustrated in the strong warming shown in Figure 5-3 where it appears that heat is introduced not only at the highest level, but also at 100 feet. Reference to the original chart record also gives the impression that warming begins at 100 ft before 146 and 170 ft. This would appear to involve direct absorption of solar radiation not only by the trees but also by the air itself a few feet above the trees.

5.2 HUMIDITY AND THE INFLUENCE OF RAINFALL ON TEMPERATURE

Rainfall amounts during successive half hours as measured at about 150 ft are plotted in Figure 5-1c. Comparison with Figure 5-1a shows abrupt drops in temperature, at all levels, associated with the onset of rain at April 190830E, April 191600E, and April 201430E. When viewed alone this evidence is inconclusive, since cooling also begins at 1600E on April 21 without rain. However the dramatic cooling between 1430 and 1530 on April 20 which is portrayed in both Figures 5-1a and 5-2 must be credited to evaporative cooling.

Further stratification of the data is revealing. Each half hour was classified as day or night, (day = 0600-1800E), and rain or no rain. Mean temperatures for each level were computed for the four categories day-and-no-rain, day-and-rain, night-and-no-rain, and night-and-rain. The results are summarized in Table 5-2.

Two hypotheses are advanced to explain the values in Table 5-2. Hypothesis I asserts that the mean temperatures during the day-and-no-rain category provide a profile of mean dry-bulb temperatures, that those during the day-and-rain category provide a profile of mean wet-bulb temperatures, and that these may be combined to compute a profile of mean dew point. Hypothesis II asserts that the mean temperatures for the

TABLE 5-2

MEAN TEMPERATURES IN DEGREES CELSIUS AT EIGHT LEVELS, RELATED TO RAIN AND TIME OF DAY

Conditions	No. of Half Hrs.	Height in ft. 6.5	30	56	74	100	146	170	192
Day and no rain	52	25.2	25.5	25.8	25.9	26.1	26.1	26.2	26.6
Day and rain	21	24.2	24.2	24.2	24.2	24.2	24.1	24.1	24.1
Night and no rain	53	23.8	23.8	23.8	23.9	23.8	23.8	23.8	23.8
Night and rain	24	24.2	24.2	24.2	24.1	24.1	24.0	24.0	24.0

night-and-no-rain category represent a radiative approach to the mean dew point profile so that each temperature is greater than or equal to the corresponding mean dew point, and the mean temperatures for the night-and-rain category provide another profile of mean wet-bulb temperatures.

Two tests of consistency may be applied to the hypotheses. The obvious one is that the two rain profiles should be identical, and this is essentially so within the accuracy of the data. The second test can be made after Hypothesis I is used to compute the profile of mean dew point. Using a psychometric chart relating dry-bulb, wet-bulb and dew point, the mean dew points as given in Table 5-3 were computed.

TABLE 5-3

MEAN DEW POINTS IN DEGREES CELSIUS COMPUTED ON THE BASIS OF HYPOTHESIS I

Height in ft.	6.5	30	56	74	100	146	170	192
Dew Point	23.9	23.7	23.7	23.6	23.5	23.3	23.3	23.2

When these temperatures are compared with line 3 of Table 5-2, it is seen that the values in Table 5-2 are greater than or equal to the mean dew points except at 6.5 ft where it is 0.1°C cooler.

While not proving the validity of the interpretation, the fact that both tests are met offers support. It is regrettable that humidity measurements were not made at all levels, but in their absence, the mean profile derived in the foregoing manner provides the best available information.

Further comparisons may be made with humidity measurements at the base camp, a clearing on the Rio León, one mile east of the north tower. At the camp, a sling psychrometer was used to measure dry-bulb and wet-bulb temperature at 0700, 1300 and 1900 EST between 12 February and 9 March 1962. The mean dew point from 82 observations was 23.2°C (73.7°F).

Using this as a reference, the mean humidity profile computed for the north tower indicates that dew point in the forest is 0.7°C higher at the surface than in the clearing and in the 50 foot layer above the jungle (146, 170 and 192 ft) is essentially the same as at the surface, in the clearing. The plausibility of these relationships lends further support to the computed mean humidity profile.

Profiles of mean relative humidity, in the absence of rain, have been computed for day and night, using the mean temperatures of lines 1 and 3 of Table 5-2, and the mean dew points of Table 5-3. The results are presented in Table 5-4.

TABLE 5-4

MEAN RELATIVE HUMIDITY AT 8 HEIGHTS IN THE ABSENCE OF RAIN, APRIL 18-21, 1962

Height in ft	6.5	30	56	74	100	146	170	192
Mean RH-day	93	91	88	87	86	85	84	82
Mean RH-night	100	100	99	98	98	97	97	96

One further comment can be made. It was anticipated that night temperature profiles would exhibit a sharp minimum at the top of the canopy as shown in Figure 2-6. The failure of this minimum to present itself is an anomaly that requires explanation since the top of the trees is the primary radiating surface at night. However, if the dew points are high at all levels, temperatures will at first cool rapidly to the dew point and thereafter at a slower rate as dew forms. Moreover the typical profile of temperature at night will then correspond in shape to the dew point profile, and evidence for differential cooling will more probably be revealed in the amount of dew deposited than in the development of a temperature minimum. It is suggested that this is the situation in the present study where high dew points at the top of the canopy prevent the cooling needed for the formation of a temperature minimum, and an inversion immediately above the canopy.

5.3 WINDS

Wind speed and direction at 200 feet were measured by the Beckman and Whitley system and recorded on a strip chart. Direction only was recorded on magnetic tape from which mean direction and the standard deviation about a 5-minute running mean were obtainable by an analog computer program. Anemometer bivanes were mounted at 6.5, 56, 74, and 146 feet. The sensor's three outputs, azimuth and elevation angles and the pulses from the propellor, were recorded on magnetic tape which was processed by an analog computer to yield the three orthogonal components $\bar{u}$, $\bar{v}$, and $\bar{w}$ and the standard deviations σ_u, σ_v, and σ_w. Unfortunately, difficulties either with the sensor's electronics or the tape recorder resulted in a disappointing retrieval of bivane data. In the case of the Beckman and Whitley system there was of course the back-up provided by the strip chart and the record is complete.

5.3.1 200-Foot Winds

The wind at 200 feet, which is a little more than 50 feet above the canopy, provides a reliable indication of the wind through the lowest few hundred feet. Although no measurements of upper winds were made it was frequently observed that the 200-foot wind was in good agreement with the movement of low scud and that this in turn was often substantially different from the slow drift of clouds at heights estimated to be above 3,000 feet.

It has already been pointed out that the northerly trade wind did not dominate the 72-hour interval as it did the dry season. This is illustrated by the 30 percent frequency of winds from the sector 320° to 040° contrasted with the 74 percent frequency between 18 February and 21 April. Wind direction at 200 feet is plotted against time in Figure 5-1d. With the northerly trade sector shaded, it is apparent that the 72-hours began and ended with northerly trades, but throughout most of the period the wind was variable.

Wind speed at 200 feet is also plotted in Figure 5-1e. The variations in speed are too random to suggest an organized diurnal pattern, or association with direction, rainfall or lapse rate. Some of these relationships are discussed in Section 3.1 where the complete record (18 February - 21 April) of the Beckman and Whitley system is analyzed to yield diurnal variations of speed, speed as a function of direction, and the frequency of various directions. There, it is shown that the minimum average wind speed of 5.7 mi/hr occurs from 0700 to 0800 and the maximum of 9.5 mi/hr from 1300 to 1600. Moreover, winds from the sector 345° to 015° are the strongest, averaging 9.9 mi/hr, and those at right angles to this sector from both east and west are weakest averaging, 2.2 and 2.3 mi/hr respectively. The average speed for the 72-hour run was only 3.7 mi/hr compared to the average of 7.9 mi/hr for the complete 2-month record. This is partly accounted for by the reduced frequency of strong northerly winds, but even these were weaker during the 72 hours than earlier in the dry season. For the complete 2-month record, the average speed of winds from the northerly trade section (320°-040°) was 9.3 mi/hr yet Figures 5-1d and 5-1e show not a single occurrence of a northerly trade even as great as 9.3 mi/hr.

One characteristic feature of wind speed is displayed during the 72 hours. In temperate zones high wind speed is associated with precipitation and one is accustomed to seeing rain slanting down. With the single exception of April 201430, Figures 5-1c and 5-1e show winds do not tend to increase at all during rain. It was altogether typical of the region that winds were usually light during rain.

5.3.2 Bivanes

Although anemometer bivanes were installed at four levels on the tower throughout the 72 hours, much less than a 72-hour record was obtained from each sensor. Reasons for this are discussed in Section 6.

Volume III of this report. When functioning properly in conjunction with the tape recorder and after appropriate processing, each sensor yielded the orthogonal components $\bar{u}$, $\bar{v}$, $\bar{w}$ and the corresponding standard deviations σ_u, σ_v, σ_w. A characteristic of the sensor was to become tail heavy during dew or rain, which made it essentially inoperative. Accordingly during dew or rain the bivane was frequently locked in a horizontal position so that $\bar{u}$, $\bar{v}$, and σ_u and σ_v could still be obtained. Then it no longer functions as a bivane. The total numbers of hours dur ıg which the bivanes were so locked are as follows:

Sensor Height in ft.	6.5	56	74	146
No. hours locked	50	44	44	15

Another type of data loss was the absence of an azimuth signal on the tape. When this happens it is impossible to evaluate $\bar{u}$ and $\bar{v}$ but the quantity $(\bar{u}^2 + \bar{v}^2)^{1/2}$ can be evaluated (i.e., the total horizontal wind speed).

There is enough horizontal wind speed data to permit some consideration of profiles. The speed at 200 feet was recorded by the Beckman and Whitley system. Mean speeds at other levels, the number of usable half hourly observations, and the ratio U_i/U_{200} for each level are given in Table 5-5.

TABLE 5 5

MEAN HORIZONTAL WIND SPEEDS DURING 72 HOUR STUDY IN FT/SEC FOR 5 LEVELS AND RATIO OF EACH TO 200-FT SPEED

Level	No. of 30 minute observations	Mean horizontal wind speed (U)	U_i/U_{200}
6.5 ft	75	0.19 ft/sec	.04
56	84	0.16	.03
74	59	0.19	.04
146	54	0.72	.14
200	84*	5.18	1.00

*The same 84 observations used at 56 ft. For the complete 72 hours the mean speed at 200 ft was 5.40 ft/sec.

SECTION 6

CONCLUSIONS

The several analyses performed on the meteorological data are summarized in the following set of conclusions.

1. An exceptionally good correlation exists between the temperature on two 200-ft towers 1100 m apart in the rain forest. It is concluded that a single tower provides representative temperatures for this environment over level terrain.

2. The lapse rate above the canopy is directly proportional to the increase in temperature from 6 to 100 ft.

3. The treetop- air interface exhibits none of the usual thermal properties of an interface which intercepts the solar radiation and emits the terrestrial radiation. Specifically the interface is neither the height of the daytime maximum, nor of the nighttime minimum, or of the maximum range of temperature; and no other height from the surface to 200 ft exhibits all these properties. The absence of the nighttime minimum is probably the result of high dew points which limit nocturnal cooling at all levels.

4. The year 1962 was normal with respect to a high frequency of northerly trades and deficiency of rain from January through mid- April.

5. The 200-ft winds revealed some evidence of steering by the broad north- south valley.

6. Wind speeds at 200 ft exhibited a rather normal diurnal pattern of afternoon maximum and morning minimum 2 hours after sunrise.

7. Winds under the canopy are very much lighter than those measured 50 ft above the canopy, being 1 to 2 percent at the 6.5 ft level and 5 percent from 50 to 75 ft.

8. Above the canopy a uniform flow of air exists as evidenced by high correlations between wind directions on the two towers at 200 and 146 ft. Below the canopy the flow is disorganized as evidenced by the low correlations found at 74, 56 and 6.5 ft and the abrupt changes in direction observed at one tower.

9. The light showers which characterize the dry season occur predominantly between midnight and 0700. The rates of rainfall observed during wet periods of March and April were not excessive but were distinguished from the rains of temperate latitudes by the absence of accompanying gales and thunder.

10. There is a rapid vertical flux of heat within the forest, as indicated by the simultaniety of temperature changes at all eight levels.

SECTION 7

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Part II contains a description of the microclimate observed from January to mid April 1962. Temperature as measured on two 200-ft towers are analyzed and compared, and it is shown that a single tower gives representative temperatures. The weather was characterized by persistent northerly trades and rainfall deficiency. Under the canopy winds range from 1 to 5 percent of the 200 ft speeds. Correlations between directions on the two towers show that below the canopy the flow is disorganized even when a uniform above-canopy flow prevails.

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